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ALTERNATIVES TO METHYL BROMIDE

“THE REMAINING CHALLENGES”

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Editors

T.A. Batchelor and J.M. Bolivar

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FOREWORD

This International Conference on Alternatives to Methyl Bromide held in Sevilla, Spain, is the fourth in the series that follows conferences held in Tenerife (1997), Rome (1998) and Heraklion (1999). These conferences have made important contributions towards Europe's commitment to phasing out the ozone depleting chemical methyl bromide (MB) for all of its uses.

Agriculture is central to life in many countries in Europe and especially Spain. As European citizens continue to strive for a better environment and quality of life, ensuring that agricultural practices do not harm the environment becomes increasingly important. Spain's leadership on environmental issues, as well as its current position as the Presidency of the European Union, make the Spanish city of Sevilla a natural host for a conference that focuses on production of high-quality food and protection of the ozone layer.

This Conference brought together farmers, researchers, extension workers and industry that have a vested interest in the successful replacement of MB with viable alternatives, particularly those working to find replacements in similar climates to EC countries bordering the Mediterranean. Participants came from all corners of the globe including Australia, China, Canada, Colombia, Mexico, Guatamala, Uruguay, Morocco, and the United States to mention just a few. There were also participants and speakers from countries that are candidates to join the European Community including Poland, Hungary, Latvia, Lithuania, Croatia and Turkey, many of whom are refining their alternatives to MB in order to harmonise their environmental legislation on this aspect with that of the EC. Most members of the Montreal Protocol's Methyl Bromide Technical Options Committee (MBTOC) attended as the Conference was useful for information on alternatives to be included in the "MBTOC 2002 Assessment" report produced for the goverments signatory to the Protocol.

Drawing on the experiences of 72 experts from 26 developed and developing countries from around the world, these Proceedings contain the papers, case studies and poster-papers discussed in plenary and workshops. The morning sessions at the conference consisted of keynote papers, overview papers and scientific papers, while the afternoons consisted of workshops. Each emphasised different topics inherent in finding alternatives to MB:

- *Keynote papers* highlighted ozone layer damage and prospects for recovery; international and national regulations affecting EC farmers; policy options that encourage alternatives; and supermarket environmental requirements.

- *Overview papers* discussed chemical and non-chemical alternatives in the production of strawberries, tomatoes, cut-flowers and vegetables; disinfestation of structures, food facilities, durable commodities and timber; and the economic and social impact of the phase out of MB.

- *Scientific papers* covered alternatives required for the continued production of important EC crops such as strawberries, cucurbits, peppers, cut-flowers, tobacco with emphasis on production in Mediterranean EC countries; and disinfestation of food facilities, grain, seeds, artefacts and timber.

- *Four workshops* on strawberries, quarantine and pre-shipment, non-chemical alternatives, and cut-flowers, were held on topics of special interest. Case studies on alternatives were presented. These workshops allowed time for ideas to be shared and discussed on the development and implementation of new alternatives. A summary of the results of each workshop was presented in plenary by the moderator of each workshop on the final day of the Conference in order to have a common view of the future work programme aimed at eliminating MB.

In addition to these activitities, 30 *posters* were displayed that supported the presentations made by experts. *Commercial enterprises* displayed materials and information on alternatives to MB. There was a useful one-day *Field Visit* involving all participants to view alternatives in action at Huelva (strawberries), Cadiz (cut-flowers and vegetables) or Sevilla environs (postharvest disinfestion).

Once in widespread use, experts attending the Conference reported on a wide range of alternatives to MB. These papers underscored that, for the vast majority of its uses, alternatives to MB exist and need to be taken up by farmers and other users. The Conference identified gaps in Europe's phase out programme where more work will be needed to find and implement alternatives. New alternatives are still being developed and some were presented for the first time at this conference. Other alternatives were more well known and the Conference heard the results of progress of trials carried out over the past 4-5 years. The challenge that lies before us is to find alternatives for all the remaining uses of MB before it is banned on 1 January 2005.

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Ozone Layer Protection
European Commission
20 February 2002

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Conference Cochair
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SUMMARY AND RECOMMENDATIONS

1. INTRODUCTION

This International Conference on Alternatives to Methyl Bromide, held in Sevilla 5-8 March 2002, was attended by almost 300 researchers, extension workers, farmers and industry representatives from 40[1] countries. The conference was sponsored by the Spanish Ministry of Agriculture, Food & Fisheries; The Spanish Ministry of the Environment; The Spanish Ministry of Science & Technology; The Consejería of Agriculture & Fisheries of the Junta of Andalusia; and The European Commission DG Environment.

Senior government officials representing the major sponsors remarked on the unprecedented integration of private and public effort underway to identify and adopt technically and economically viable alternatives to methyl bromide (MB) before its phase out in 2005 in developed countries. They noted that alternatives were required to maintain Europe's compliance with the Montreal Protocol and with national obligations under Regulation EC2037/00 on the phase out of ozone depleting substances.

Drawing on the experiences of 72 experts from 26 developed and developing countries from around the world, these Proceedings contain the papers and case studies discussed in plenary and workshops. Four workshops discussed the use of non-chemical alternatives; and alternatives to MB for strawberry fruit and mother plant production, cut-flowers, and quarantine and pre-shipment uses. Commercial enterprises displayed material and information on alternatives to MB. Participants saw pest control methods used in a rice packing facility and viewed alternatives in use or under development for producing strawberries, cut-flowers and vegetables.

This summary and recommendations was drafted and discussed with participants in plenary on the final afternoon of the conference.

2. OZONE DEPLETION

Experts on ozone depletion noted that the ozone layer is not yet showing signs of recovery. Ozone changes observed over the last two decades have led to an increase of 5-15% in the year-round, biologically relevant UV radiation doses over large parts of Europe. The increases have been greatest in springtime and in northern and central Europe. Climate-chemistry models, which include changes in the concentrations of greenhouse gases and halogenated compounds, indicate that UV radiation may continue to increase in the coming 10-20 years during springtime at high latitudes. Higher UV radiation contributes to further risks to human health. There is scope for a UV forecasting system for Europe which, when coupled with advice on how to avoid damaging UV-radiation, would reduce health risks to citizens.

Control measures under the Montreal Protocol have established phase out schedules for MB except for QPS uses. Regulation EC2037/00 has also set a cap on the amount of MB that could be placed on the EC market for QPS. In 2001, the amount licensed to be placed on the market in the EC was 14% below the cap for QPS uses and 17% below the cap for non-QPS uses. A recent survey of Member States (MS) still consuming MB reported that most MS expected to have alternatives in place for most of the MB uses by 2005.

3. FRUIT, VEGETABLE AND CUT-FLOWER PRODUCTION

Strawberry, tomato and cucurbit production in Europe was reported to consume about 60% of the MB in the EC, predominantly in Spain, Italy, France, the UK, Belgium, Greece and Portugal. Other crops important to many MS are peppers, eggplants, cut-flowers, and tobacco which consumed about 40% of the MB in the EC.

[1] Australia, Austria, Belgium, Bulgaria, Canada, China, Colombia, Costa Rica, Croatia, Cuba, Cyprus, Denmark, Egypt, France, Germany, Greece, Guatemala, Honduras, Hungary, Israel, Italy, Jordan, Kenya, Latvia, Lithuania, Macedonia, Malaysia, Malta, Morocco, Mexico, Philippines, Netherlands, Poland, Portugal, South Africa, Spain, Turkey, United Kingdom, United States of America and Uruguay

3.1 Strawberries

About 80% of the fresh-market strawberries produced in Spain are sold within the EC. Strawberry production is the single largest consumer of MB in Spain. Trials carried out in the past 4 years have shown the following treatments as the most promising alternatives for fruit production in Spain: 1,3-D + chloropicrin under polyethylene film (PE) or Virtually Impermeable Film (VIF), dazomet alone, solarization + shank-application or drip irrigation of metam sodium, solarization + biofumigation using chicken manure. Efficacious treatments require careful application techniques and soil preparation. For mother plant production in Spain, the most promising alternative was 1,3-D with chloropicrin broadcast shank-applied under PE or VIF.

Combination treatments were considered the most promising in the USA using 1,3-D + chloropicrin, or chloropicrin alone sometimes followed by metam sodium, but the future availability of fumigants depended on the result of periodic regulatory reviews.

Some experts stressed the importance of disease-free mother plants in order to maintain profitability in the production areas while others thought that production of mother plants using MB after 2005 might be considered as a future Critical Use application if further research was not successful. Poland reported Integrated Fruit Production as the most promising technique for eliminating the use of MB and other soil fumigants in strawberry production. Experts from Spain and Poland considered soilless culture without MB had potential for fruit and mother plant production. Soilless culture is widely used in some countries e.g. The Netherlands. In Spain, the substrate material could be peat, coconut fibre, grape bagasse compost or composted cork.

Experts from Morocco reported solarization alone, or combined with metam sodium or 1,3-D, were similar to MB for nematode and weed control, yield, and profitability in strawberry production. Morocco aimed to phase out all major uses of MB well before 2015 in order to avoid further dependency on MB and possible importer boycott of products grown with MB.

Azides, iodomethane and other products under development were considered potential alternatives for the control of fungi, bacteria, nematodes and weeds.

3.2 Tomatoes

Tomatoes were reported to occupy 14% of the horticultural land and to contribute 23% of the value of Spain's horticultural production. About 25% of the fresh production and 50% of the canned fruit are shipped out of Spain. Experts commented that Spain does not rely on MB for tomato production. Crop management systems for tomato production require hybrid varieties with resistance to pathogens and soil fumigation with other conventional fumigants. New "long life" varieties that contain the *Mi* gene are resistant to *Meloidogyne* spp. Almeria province, a major production region, does not use MB for the production of vegetables.

The existing and potential alternatives to MB in Mediterranean countries to control tomato soilborne pathogens were summarised and included the use of resistant cultivars, grafting, organic amendments (biofumigation), crop rotation, soilless culture, physical treatments (solarization, steam, flaming) biological control (e.g *Verticillium* fungus used to control *Meloidogyne javanica* nematodes in unheated plastic houses for tomato production), chemical alternatives (chloropicrin, 1,3-D, dazomet, metam-sodium), and combinations of these treatments. The success of the alternative depends on its use within an integrated pest management (IPM) programme that includes sanitation, pathogen-free seeds and seedlings, weed control and other activities.

Impermeable plastic, singularly or combined with biocontrol agents or chemicals during solarization in Greece, reduced the disinfestation period on land for tomato crop production from six to three weeks.

In Italian-grown tomatoes, soil solarization alone or in an IPM programme with chicken manure (biofumigation), biological antagonists, resistant/tolerant varieties and rootstocks, or by reduced dosages of chemicals, resulted in good pest and pathogen control with profitable yields for specific crops and situations.

In Turkey solarization, alone or in combination with other treatments such as metam-sodium, 1,3-D, dazomet and biofumigation, were reported to be used as part of an IPM programme for managing soilborne pests in tomato and cucumber production.

In Cuba weeds were controlled non-chemically in vegetables by disrupting their seed development or by drying them. Crop rotation, solarization, crop resistance, biological control, limited chemical intervention, and organic substrates were used to control nematodes. Grafted plants and bio-fumigation were reported to be under evaluation for use on protected crops such as tomato, pepper, water melon and cucumber. The floating tray system is being adopted widely in Cuba and is successfully eliminating MB in the tobacco sector.

3.3 Peppers

In Spain, greenhouse sweet pepper grown in soil treated with 1,3-D + chloropicrin applied by drip irrigation under PE plastic produced results similar to MB. Biofumigation with solarization, using fresh sheep manure and chicken manure or soybean flour, was reported to give satisfactory pathogen control and production similar to MB. When the applications were repeated there was an improvement in efficacy against pathogens, yield and physico-chemical characteristics of the soil. This was considered to be a viable alternative for sustainable and organic agriculture. Grafting was another alternative which provided satisfactory soilborne pathogen control and acceptable yield.

3.4 Other vegetable crops

France reported a decline in the use of MB in vegetable crops due to increased production areas using substrates, and due to increases in the price of MB compared to the alternatives dazomet, 1,3-D, metam sodium, solarization and steam. Grafting as an alternative to MB provided satisfactory soilborne pathogen control and acceptable yield.

Belgium reported a reduction in the use of MB due to adoption of substrates such as rockwool, grower fears about exceeding bromide residues in MB-fumigated crops, exclusion of MB from crops grown organically and a decline in intensive agricultural land. New horticultural methods under development tried to eliminate MB from the production system but MB is currently used as a 'correction tool' for otherwise uncontrollable situations.

3.5 Cut-flowers

Results on alternatives to MB for cut-flowers produced in Europe (Hungary, Italy, Spain, Portugal and Greece) and Latin America (Colombia and Guatemala) indicated that the main pests requiring control are fungi such as *Fusarium oxysporum f.s. dianthi* (F.o.d), *Phytophthora* spp, *Pythium* spp., *Sclerotinia sp.*, *Verticillium dahliae* or *Rhizoctonia solani*, weeds, nematodes especially *Meloidogyne* sp., pests and bacteria such as *Agrobacterium* spp. Crops such as carnation, gerbera, roses, chrysanthemum and snap dragon were grown mostly in greenhouses in soil, but more recently there was increased production using soilless culture.

Depending on circumstances related to environmental conditions, supplies, available infrastructure and other factors, experts reported on a number of MB alternatives used around the world to grow cut-flowers. Alternatives include steam, solarization, biocontrol, substrates, organic amendments, crop rotation, resistant varieties, biofumigation, metam-sodium, 1,3-D, dazomet and chloropicrin. The best results are obtained by an integration of these alternatives. An expert from Colombia described the advantages and disadvantages of steam, compost, soilless cultivation and fumigants for cut flower production. Colombia is the second largest cut-flower exporter in the world and does not use MB for their production.

In Spain, a mixture of 1,3-D + chloropicrin controlled F.o.d in carnations to a similar level of efficacy as MB. The method of application was important for ensuring treatment success. Inconsistency in results was attributed to poor application technique or susceptibility of the particular cultivar to this disease. Shank application covered with VIF film controlled nematodes, insects and some fungi and weeds. Solarization + poultry manure reduced F.o.d but did not control the disease below the threshold required. Other results showed good control of diseases and nematodes and productivity was maintained. Resistant cultivars were effective but presented a limited spectrum of resistance and there was a high cost of selection for acceptable marketable quality and yield.

Metam sodium and dazomet controlled weeds, fungi and nematodes, but did not control sufficiently Fusarium and Verticillium Wilts. Metam sodium with VIF plastic controlled *Phytophthora cryptogea* in gerbera but the requirement for a plastic cover reduced acceptance to growers.

Steam was considered a good disinfestation system but could be cost-effective depending on the circumstances. Steam was considered economically feasible as an alternative when it was included as part of a sanitation programme. Organic amendments using composted plant material remaining from the cut-flowers was used at some locations. Biological control using non-pathogenic *Fusaria*, *Agrobacterium radiobacter* or parasites of pests was reported to control specific problems in cut-flower crops. Integration of two or more alternatives such as resistant cultivars, soil less culture, steam, solarization, biocontrol agents and chemicals should be considered as a global strategy for replacing MB in cut-flower production.

4. NON-CHEMICAL TREATMENTS

Many papers and most posters provided information on non-chemical alternatives to MB such as steam and soilless systems. For example, strawberries, sweet peppers, carrots and carnations were produced using non-chemical methods in Spain; strawberries in Australia and Turkey; tomatoes in Morocco and Italy; vegetables in Cuba, Uruguay, Australia, Poland, Turkey and the USA; melon in Italy; and tobacco in Cuba, Spain and other countries.

Experts reported research on agricultural waste e.g., rice hulls, almond hulls, coconut fibre, seaweed in Spain, as well as research on biofumigation, organic amendments, solarization, grafted plants and biological control products. Some techniques provided good control of pathogens, while other techniques required further development. Apart from steam and soilless systems, most techniques are used in combination to control a range of pests/diseases. Combination treatments were more knowledge-intensive and required more skill than application of MB.

Solarization is being used by about 80% of farmers in Jordan Valley. Biofumigation, alone or in combination with solarisation, in appropriate circumstances was reported to be as effective as conventional pesticides in the control of fungi, nematodes, insects and weeds. Gross income in tomato and melon crops in Uruguay was greater using biofumigation than conventional pesticides. It was recommended that biofumigants should be produced locally in order to reduce costs.

Solarization + biofumigation or organic amendments are being used in Spain (Murcia region) to produce sweet pepper, some specific types of tomato and outdoor lettuce.

Plants grafted onto resistant rootstock, and normally combined with other techniques, is used to produce some tomatoes and most of the watermelon crop in Spain.

Substrate systems are used to produce 3,800 ha of tomato, 270 ha sweet pepper about 40 ha of greenhouse sweet pepper in Spain. An expert from Jordan reported limited use of substrates to grow unprotected crops cheaply.

Steam is used in Spain on ornamentals such as carnations as an alternative to MB.

In Spain, the floating tray technology is used to produce 98% of the tobacco seedlings without MB. Similarly, crop rotation avoids the requirement for MB in Spain (Almería) and is used in the production of 7,000 ha of pepper, tomato, cucurbits and broccoli. Direct seeding, animal manure + plastic mulch used for watermelon production in some areas in Mexico; growth promotors plus animal manure are also successful for producing water melon in other areas.

5. POSTHARVEST TREATMENTS

The advantages and disadvantages of alternative chemical fumigants, biological control agents and physical treatments were discussed as potential alternatives to MB for durable commodities, timber and timber products. Phosphine, controlled atmospheres and sulfuryl fluoride (separately) have been used for many years for disinfesting durable commodities, timber and structures. Sulfuryl fluoride was recently granted an experimental use registration in the US allowing its use to be extended to include food (walnuts and raisins). Trials were reported to be ongoing on food products and mills in a number of countries as part of the registration requirements for this product.

Experimental trials on microwave technology for rice disinfestation in Spain was reported. There was also reports on the development of two new fumigants - carbonyl sulfide and dimethyl disulfide.

The large range of products of relatively small volume and a highly fragmented industry presents difficulties for meeting registration costs of new chemicals. Research to preserve wood using biological agents or natural products that have low-environmental impact was considered a priority due to uncertainties in re-registration of chemical products under the EC Biocidal Products Directive 98/9/EC.

Often disinfestation treatments must be undertaken rapidly to minimise delays in marketing recently imported but insect-contaminated products, and many treatments were reported to be not as rapid as MB. Pre-export treatment or fumigation in-transit were considered to be possible ways to overcome the lack of speed of action of alternatives.

Under regulation EC2037/00 the quantity of MB that can be consumed within the EC for QPS purposes has been capped. Most Member States reported in an EC survey that research was being undertaken on QPS alternatives. An expert from the United States reported that the US has an active research programme for developing MB alternatives. About 30% of the MB consumed in the United States was used for postharvest and structural treatments. For perishable commodities, the United States permits heat, cold and irradiation as non-chemical treatments that would meet quarantine standards, provided monitoring and verification were carried out to high standards.

Humidified nitrogen and carbon dioxide with low oxygen levels, or heated and humidified air, were considered replacements for MB for controlling pests in artefacts in museums.

Fumigation using 2% phosphine and 98% CO_2 over 14 days was reported to successfully control pests in grain in Australia and Cyprus. Fumigation with low phosphine concentrations + 3-5% CO_2 + elevated temperatures over a 24 hour period is becoming more common in the United States. The cost of the fumigation is comparable to MB. Experts at the Conference reported on the importance of sanitation and inspection for all pest control operations, even for old mills where sealing was difficult, as these activities largely eliminated the need for pesticide treatments including disinfestation using MB.

Manufacturers of alternatives for stored products and structures pointed out that any annual critical use exemption to allow the continued use of MB in this sector after 2005 could delay manufacturer investment in facilities to manufacture alternatives.

An expert from Spain reported that MB was used as a quarantine treatment on imports of oak logs or wood packages that were not treated at origin, and on a minor number of exports such as garlic destined for Brazil and chestnuts to Mexico. MB fumigation of timber has been substituted with mechanical methods such as de-barking or heat treatment. Cold treatments are used on exports of citrus to meet the requirement for freedom from live Mediterranean fruit fly. Export grains are treated when necessary with phosphine instead of MB.

Similar disinfestation treatments were under consideration for use in developed and developing countries. However, the most applicable for developing countries appeared to be those that were low cost and easily-handled technology such as the flexible PVC cocoons that disinfest products in about 2-7 days at 30ºC under vacuum; or the hermetic systems used extensively in Cyprus.

6. ECONOMIC AND SOCIAL IMPLICATIONS

The Spanish national project to find alternatives to MB was launched in 1997 with the short-term objective of finding alternatives to compensate for the reduction and ultimate cessation of the use of MB. Results achieved so far have overcome some of the fears expressed by the producers of strawberries and peppers under glass who were reported to be the main MB users in Spain. Despite this progress, an expert from Spain considered that further research would be required to ensure the economic viability and environmentally-friendly production of these and other crops.

Trials and demonstrations on MB alternatives that resulted in the phase out of MB can be accompanied by other useful activities such as the distribution of informational materials on alternatives, the use of economic incentives, encouragement for companies to review their policies and contracts relating to MB use, and the development of new industries to provide alternative products and services in rural areas.

As research has progressed on alternatives to MB, the estimate of the economic impact of the ban in the United States on its use have been revised from about $1.5 billion to $624 million annually using a value of marginal product approach. Sixty-nine percent of the economic impact will be incurred when the final 30% reduction is required in 2005 in the USA. Permitting quarantine uses and critical use exemptions in the United States may lessen the economic burden until new pest control strategies are adapted for use.

The most important vegetable crops grown in Hungary are white-yellow sweet paprika, tomatoes, hot green paprika and cucumber. These crops are grown year-round using thermal energy from natural underground springs. Rockwool and grafted plants are being adopted in Hungary. They are cost-effective and offer the best promise for eliminating the remaining uses of MB in this sector by 2005.

A questionnaire sent to 504 strawberry growers in Spain asked questions on the structure of farms, aspects concerning the adoption of innovation and management, sociocultural characteristics of the grower, soil disinfection procedures, and their willingness to pay for an alternative to MB. About 70% of growers were will to pay extra for MB alternatives. Owners of properties more than 8 ha, those involved in IPM production practices, and those that attended seminars on alternatives to MB were more likely to be willing to pay for an alternative.

EUREPGAP was set up by retailers to provide global agricultural production standards and a verification framework for fruit and vegetables to retailer and supplier members. Written evidence from growers is required for the use of soil fumigants such as MB including information on the pest problem, location, date, active ingredient, doses, method of application and operator. EUREPGAP recommends that growers demonstrate to the certifier that alternatives to MB have been explored by showing their technical knowledge and written evidence of alternatives to soil fumigation. Chemical fumigation of soils needed to be justified and used only as a last resort, and recommended alternatives to MB such as crop rotation, planting of break crops, use of disease resistant cultivars, solarization, conversion to soil-free cultivation and similar techniques. EUREPGAP recommendations are currently voluntary but may become compulsory in the future.

Almeria produces 70% of Spain's vegetable exports. Eighty per cent of both producers and exporters in Almería,are represented by the Association of Harvesters and Exporters of Fruit and Vegetables (COEXPHAL). Growers since 1997 had been requested not to use MB. Alternatives have successfully replaced MB based on a new agreement on the appropriate measures to be taken reached jointly by COEXPHAL and different chains of supermarkets that aim for a balance of environmentally sound alternatives, quality products and profitable production methods for growers. Growers must fulfil specific requirements that comply with rules in order to be certified.

More than 40 demonstration projects on alternatives to MB have been carried out in developing countries by UNIDO, UNDP, the World Bank and GTZ. More than 10 alternatives had been tested for their usefulness as both soil fumigants and for the treatment of commodities. The most suitable alternatives to MB had been selected by local farmers and other stakeholders in order to initiate phase-out programmes in more than 22 developing countries e.g, Morocco, Jordan and Turkey. Partial phase-out of MB had already taken place in certain developing countries based on financial assistance provided by the Montreal Protocol's Multilateral fund.

7. RECOMMENDATIONS

Discussions over four days showed that significant progress has been achieved in the identification and development of alternatives to MB. In some countries, alternatives are widely used. In most other countries alternatives are used to some extent and can be adopted much more widely. The conference organisers received recommendations from some conference participants and can therefore support the following:

1. That measures need to be put in place to train growers on how to use alternatives, in order to ensure the adoption and sustainability of alternatives by 2005. This could include, for example, growers with experience of alternatives training other growers in the adoption of alternatives;
2. That work on MB dosage reductions should be discontinued unless justified because MB will not be permitted in 2005 for non-QPS uses and instead all further research should focus on alternatives;
3. That application techniques for alternatives should be improved in order to enhance efficacy and consistency, simplify procedures for the grower, improve the accuracy of the technique, improve worker efficiency and safety, and improve profitability;

4. That methods to avoid the need to apply chemical fumigants, and combination methods that miminise chemical input, should be given high priority;
5. That development of 'fast-track' registration procedures for MB alternatives is established in the European Community;
6. That each Member State should maintain records of the adoption of alternatives including hectarage covered, grower adoption and quantity of ODS replaced by the alternatives in order to set priorities for further research and grower training;
7. That agricultural verification and certification systems should be encouraged as they can effectively promote the use of alternatives to MB by more growers and organisations;
8. That manures and other animal-derived products that can contain contaminants should be used only within strict guidelines for environmental protection and human safety;
9. That research should be undertaken to better understand the mode of action of non-chemical alternatives in order to use them more effectively in the future for controlling pests in more crops and climatic situations; and
10. That examples drawn from countries that already have alternatives to MB in use in the flour and milling industries and other sectors that are seen as 'challenging' in order to develop sustainable systems for all countries.

AN OVERVIEW OF THE SCIENTIFIC ASPECTS OF OZONE DEPLETION AND THEIR IMPACT ON THE ENVIRONMENT

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ABSTRACT

This paper describes the protective action of stratospheric ozone together with different mechanisms causing ozone depletion. Ozone absorbs UV radiation coming from the Sun. Increased UV radiation due to ozone depletion affects people, terrestrial and aquatic ecosystems, materials as well as air quality. Chlorofluorocarbons, halons and methyl bromide are all significant ozone depleting substances controlled under the Montreal Protocol. Satellite observation systems help to predict future changes to the ozone layer. Based on agreements under the Montreal Protocol, the ozone layer is expected to recover toward the middle of the 21st century.

Keywords: ozone, ozone depletion, UV effects, UV absorption, ozone environmental effects, remote sensing.

INTRODUCTION

In 1974, F.S. Rowland and M. Molina published in "Nature" their ideas on the influence of the chlorofluorocarbon (CFCs) on ozone depletion. These gases are used as propellants in spray cans, as well as a cooling medium in air conditioning systems and refrigerators. As might have been expected, this study was not at all welcomed by the industry. However, when in 1985 Farman and their colleagues of the British Antarctic Survey announced the existence of the ozone hole in the Antarctic, and the extension and depth of this phenomenon was confirmed by measurements taken by the Total Ozone Mapping Spectrometer probe (TOMS) on board the NASA's Tiros-7 satellite, the world knew that this was the beginning of a new and serious problem. Further measures carried out later both from the Earth and from satellites have come to confirm the importance of this "hole" which has already caused a 70% reduction of the Antarctic ozone. With an extension of $27x10^6$ km^2, it even affects the southern areas of South America and Australia.

Further measures taken worldwide have proved that ozone depletion is a general problem that, with more or less intensity, affects the whole globe. The original cause seems to be always the same one: the photolysis of compounds of anthropogenic (man-made) origin which, due to their high stability, manage to reach the stratosphere. Here, under the action of UV radiation, Cl and Br are given off, giving rise to cyclic reactions whose result is the ozone depletion and whose basic equations are presented below. The UV radiation increase thus created affects all living beings and all ecosystems: terrestrial and aquatic. It even affects micro-organisms, phytoplankton, inert materials and the quality of the air we breathe. After a brief analysis of these effects, I discuss future changes to the ozone layer in the light of the current observations and agreements to reduce ozone depleting substances under the Montreal Protocol.

In 1995, Molina and Rowland were granted the Nobel Prize for their discovery, which came to corroborate its importance.

THE OZONE PROTECTIVE EFFECTS: UV RADIATION

It is important to point out that the ozone presence in the atmosphere can be beneficial or harmful, depending on how high it is. The tropospheric ozone, which is close to the ground, is harmful both for living beings and materials due to its highly oxidising effects. It represents approximately 10% of the Earth's total ozone. The remaining 90% forms the stratospheric ozone layer, between 20 and 30 km high approximately. It is beneficial because it protects the Earth's surface from the UV radiation coming from the Sun, which has a large energy and is capable of causing damages to living beings and materials.

These two "types" of ozone can also be differentiated by their origin. The tropospheric ozone has a photochemical origin and it is produced out of the pollutants which are given off into the atmosphere from different sources, mainly from road transport and thermal power plants. On the other side, the stratospheric ozone originates in a creation-destruction process.

It is created when the UV radiation with a wavelength λ < 242 nm reaches the oxygen molecules which are present in the upper stratosphere, given place to the reactions:

$O_3 + h\nu \ (\lambda < 242nm) \rightarrow O+O$ (1)

$O_2 + O + M \rightarrow O_3 + M + energy$ (2)

Ozone is produced by by breaking the oxygen molecule (assisted by highly-energy UV radiation) to form atomic oxygen (O) which then combines with molecular oxygen (O_2), using an external molecule M acting as a catalyst. The balance is kept with a series of the destructive reactions:

$O_3 + h\nu \ (200 < \lambda < 310nm) \rightarrow O_2 + O\ (^1D)$ Hartley's band (3a)

$O_3 + h\nu \ (319 < \lambda < 350nm) \rightarrow O_2 + O\ (^3D)$ Huggins' Band (3b)

$O_3 + O \rightarrow O_2 + O_2$ (4)

"D" means that the resulting atom is in an excited level (Chapman 1930). These reactions show UV radiation absorption by part of the stratospheric ozone in two spectral intervals called Hartley's band and Huggins' band respectively. This mechanism enables the Earth's surface to escape the harmful action of such an energetic radiation, elevating, at the same time, the stratosphere temperature.

OZONE DEPLETION MECHANISMS

The mechanism described in the paragraph above is a balanced process *per se*. It naturally depends on the intensity of the affecting radiation but it balances in a natural way so that the ozone quantity in the stratosphere should remain stable through time. It is higher in the poles and lower in the tropics and it has seasonal changes but locally it should be constant.

However, a series of man-created organic compounds have managed to reach the stratosphere and go over the tropopause, the highest stratosphere border situated approximately 10 km above the Earth. There, under the action of strong UV radiation, they cause "ozone depletion". These chemical compounds are generally called ChloroFluoroCarbons, CFCs. They were invented in 1928 and from 1950 have been produced in great volumes due to their commercial properties. They are commonly used industrially as refrigerants, solvents, different types of foam, aerosol sprays, disinfectants, fast-food containers and pesticides. CFCs are also highly stable which enables them to reach the stratosphere and to live a long time in the turbulent atmosphere. The most important ozone depleting substances are CFC-11, CFC-12, CFC-13 and halons which also contain bromine and are used for firefighting.

In reality, CFC's do not destroy the ozone directly, but they are photolysed in the stratosphere through the UV radiation action, freeing chlorine. A large part of this chlorine ends up as Hydrogen Chloride, HCl, or Chlorine Nitrate, $ClONO_2$. These substances are called "reservoir species" and do not react directly with the ozone. Instead, they are decomposed by the UV radiation, giving place, among others, to the atomic Chlorine, Cl, and Chlorine Monoxide, ClO. The final result is that, either through the CFC's direct catalysis or through the decomposition of the reservoir species, free atoms of Cl and ClO appear in the stratosphere which, together with the atomic oxygen, O, coming from the O_2 photolysis (reaction 1), catalyse the ozone destruction through a series of complex and not entirely known mechanisms which could be, nevertheless, represented in a simple manner through the following set of reactions:

$2Cl + 2\ O_3 \rightarrow 2ClO + 2\ O_2$ (5)

$2\ ClO + 2O \rightarrow 2Cl + 2\ O_2$ (6)

Net Reaction: $2\ O_3 \rightarrow 3\ O_2$ (7)

Notice that the Cl acts as a catalyst so that at the end of the process it is ready to be re-initiated and therefore does not disappear. This makes it possible for a single atom of Chlorine to destroy millions of ozone atoms before disappearing. The removal mechanism involves the formation of HCl:

$OH + ClO \rightarrow HCl + O_2$ (8)

$O_2H + Cl \rightarrow HCl + O_2$ (9)

Since the HCl is soluble in water, it is eventually eliminated from the atmosphere through precipitation. This is a very interesting reaction since it is one of the means through which the excess of Chlorine in the atmosphere can be cleaned.

Though there is no doubt whatsoever that the Antarctic's ozone hole is due to the CFC's devastating action, this evidence is not so consistent in other latitudes even though there is a general consensus. Leaving natural variations aside, between 1979 and 1991 the total column ozone went down in the mid-latitudes (25-60º) 4.0, 1.8 and 3.8% each decade respectively, for northern mid-latitudes in winter/spring, northern mid-latitudes in summer/ fall and southern mid-latitudes year round. However, from 1991, the decreasing rate has slowed down. The observed total column ozone losses from 1979 to the period 1994-1997 are about 5.4, 2.8 and 5.0% respectively, for the same areas and periods mentioned, which represents a fall in the decreasing rate of 2% approximately.

The destructive effect of the CFC's can be quantified through the "Ozone Depletion Potential", ODP. Typically, it is considered that the CFC-11's ODP is 1.0, and therefore, the action of the remaining ones is taken in relation to the CFC-11. An ODP of 2.0 means that such a compound is twice as 'bad' as the CFC-11. Thus, the ODP of a substance "X" is defined as the relation between the total ozone loss caused by "X" and the total ozone loss caused by the CFC-11. The CFC's have an ODP of around one, whereas the halons, which contain bromine, are much worse. Halon-1211 has an ODP of 3.0, Halon-1301 has an ODP of 10.0 and Halon-2402 has an ODP of 6.0. This is due to the fact that the Bromide does not give rise to reservoir species. Instead, it is directly photolyzed, giving place to similar reactions to those in (5-7).

MB, first listed by the Montreal Protocol as an ODS in 1992, has an ozone depletion potential (ODP) of 0.6 in the Protocol. This was lowered by the Protocol's Science Assessment Panel to 0.4 based on more recent information. However, 0.4 is still considered a significant ODP necessitating the phase out of MB.

ENVIRONMENTAL EFFECTS

The ozone depletion environmental effects are directly derived from the corresponding UV radiation increase which affects as much living beings as materials. The UV radiation is typically divided into three intervals:

UVC: λ<280 nm UVB: 280 nm <λ< 320 UVA: λ > 320nm

The UVC is practically entirely absorbed by ozone whereas UVB and UVA, even being partially absorbed, reach the ground. Although UVB, which is more energetic, is supposed to be the worst, recent studies affirm that UVA also affects DNA. Since not all wavelengths have the same effect on living beings due to their different energy, the product of this biological effect by the radiation intensity is known as "erythermal radiation". The increase in this erythermal radiation with respect to the 1970 levels reach 130% in the Antarctic, 22% in the Arctic and 7% and 4% in the Northern Hemisphere winter/spring and summer/fall, respectively. In certain regions of Central Europe increases of over 50% have been punctually measured for ozone reductions of 30%. The relation between the ozone depletion and the increase of the erythemal radiation has been perfectly proved in a large number of places. Such outstanding increases in the radiation intensity affect human health, especially three major organ systems whose cells and tissues are exposed to the Sunlight: the eye, the skin and the immune system. Certain molecules present in these organs called chromophores, are capable of absorbing certain wavelengths, giving rise, through photochemical reactions, to photoproducts. The latter ones cause a biochemical change in the cell, causing either death or permenant alteration. The final result is the whole organism's response which translates into changes in the DNA.

Most skin cancers can be classified into three groups: Basal Cell Carcinomas, BCC, approximately 80%, Squamos Cell Carcinomas, SCC, 16% and Melanomas, 4%. In the USA, more than 90% of skin carcinomas are considered to be caused by UVB. Fortunately, they are not usually fatal when treated on time. Eyes suffer from cataracts and carcinogenesis in the cornea and the choroid. The relation seems to be well established. Besides, these kinds of affections, which used to appear over the age of 60, are now relatively frequent at 40.

Logically, such effects also happen, to a higher or minor extent, in domestic animals. SCC associated to elevated exposures to radiation has been reported in cattle, horses, cats, dogs and other animals.

The terrestrial ecosystems, including plants and microbes, also suffer the effects of UVB radiation increase, though these micro-organisms can also develop some defences. The balance between damage and protection depends on the species and it seems quite clear that it affects through altered patterns of gene activity rather than damage. Such auto-regulative effects become apparent in many different ways, including changes in life cycle timing or in the shape or production of plants. The effects on insects and microbes are also considered to be possible. Analysis of its effect on trees is more difficult, though long natural exposures to UVB are considered to facilitate the attack of insects and pathogens.

Recent studies have proved that UVB and UVA have adverse effects on the growth, photosynthesis, protein and pigment content and reproduction of phytoplankton, thus affecting the food web. The macroalgae and seagrasses also show great sensitivity to UVB. The same can be said about zooplankton and other organisms, such as urchins, corals and amphibians.

Some materials, such as polymers, are also affected in a negative way by UVB radiation and, indirectly, the art heritage also suffers the damages through UVB influence on the air quality. The increase of UVB makes the chemical activity in the troposphere increase, elevating the local concentrations of ozone in highly polluted areas which, considering its oxidising nature, become a highly damaging pollutant not only for materials, but also for health. In this way, a great number of monuments that have remained unharmed over the centuries have recentlyh undergone tremendous damage in just a few years, such is the case of the Aqueduct in Segovia.

THE FUTURE

Since the problem of ozone depletion appeared, extraordinary efforts have been made, both at a political and at a scientific level, to bring a solution. From the scientific point of view, a great number of laboratories have done research trying to work out not just the mechanisms which produce it, its effects and the possible alternatives to the CFC's, but also experimenting and measuring. As it is a global problem, the solution has to be a global one too and the spatial remote sensing was the answer. After flying on board the Tiros-7, the TOMS probe has kept measuring day to day the thickness of the ozone on board the Russian Meteor or the Japanese ADEOS. The SBUV probe has done the same on board the NOAA satellites; the UARS transported the HALOE and CLAES probes to measure the concentrations in the high troposphere of a large number of the compounds involved in the ozone depletion. The recently launched TERRA carries the MOPITT probe on board and the future CHEM, from the EOS programme, will be specifically dedicated to the atmospheric chemistry. The ENVISAT, which will be launched by the European Space Agency this year, carries the GOMOS and the SCHIAMACHY on board in order to measure the ozone and dozens of other different compounds. In conclusion, there is a huge amount of information and talent dedicated to the search for solutions.

The Montreal Protocol, signed in 1987, just two years after the discovery of the ozone hole, seems to be really effective. Examples of its adaptation to the reality are the successive amendments introduced in 1990 in London, 1992 in Copenhagen, 1995 in Vienna, Montreal in 1997 and Beijing in 1999 which have been more and more rigorous and responding with agility to the new knowledge. The ozone layer keeps being depleted, but at a lesser rate. The chlorine concentration is also being reduced, though not the bromine. The concentration of the CFC's substitutes is increasing and, in conclusion, the problem seems to be properly channelled. Despite all that, the consequent increase of UVB radiation is expected to keep affecting the ecosystems. The EPA estimates that a 2% increase in radiation will cause an increase of 2 to 6% of non-melanoma skin cancers and, obviously, these increases will also cause other damage.

Finally, we could ask ourselves: will the ozone layer be regenerated? If the Montreal Protocol is observed, yes, but many of us will probably never see it. The maximum ozone depletion is supposed to be reached during this or the following decade, that is, it will still keep being reduced for a few more years. It must be kept in mind that the cause is the excess of Cl and Br in the stratosphere. What is being done is to slow down or halt the Cl and Br emissions, but we must wait for the Nature to "clean" these substances from the stratosphere. And that has a rhythm that cannot be altered. The new substances take in between 3 to 6 years to reach the troposphere and it is then when the Cl and Br concentrations would start to weaken. The CFC's time of permanence ranges between 50 and 100 years.

In conclusion, it is a problem whose solution requires patience, but that could be solved by the mid 21st century.

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DOCUMENTING UV RADIATION TO SUPPORT IMPACT STUDIES AND HEALTH PROTECTION FOR CITIZENS

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ABSTRACT

The UV spectral range is divided in three sub-regions consisting of UV-C (200 to 280 nm), UV-B (280-315 nm) and UV-A (315-400 nm). Humans can protect against harmful UV exposure by using UV blocking creams, wearing a hat and sunglasses and avoiding exposure when the radiation is highest. To better quantify UV radiation for its erythemal effects, an action spectrum has been determined that attributes an efficiency factor to each wavelength. To ease the use of the information by the public, WMO has also defined a UV index by mapping the erythemal irradiance on a simple scale ranging from 0 to 10 (in Europe). Solar light intensity is influenced by solar zenith angle, total column ozone, clouds, aerosols, altitude and surface reflectance. Broadband radiometers, multi-channel medium-spectral-resolution instruments and high-resolution spectrometers measure surface UV radiation, often linked into cross-country networks. An increasing number of weather services provide next-day forecasts of UV radiation intensity, usually in the form of a UV index. The forecast can be based on radiative transfer modelling using forecasts of ozone and cloudiness, while others rely more on statistical analysis of long time series of ground UV measurements, combined with the weather forecast. Scientific research on UV radiation and impact studies on the environment and human health contribute toward advice to the public on how to behave safely with respect to UV exposure.

Keywords: UV radiation, sunburns, skin cancer, environment, UV measurements, modelling, UV forecasts.

INTRODUCTION

In terms of energy, the ultraviolet part (wavelengths from 200 nm to 400 nm) of the solar light that reaches the Earth's surface represents only a small fraction of the total but it has an important impact on living organisms. Life as we know it would actually not be possible if the UV radiation was not considerably attenuated by the atmosphere and in particular by absorption in the stratospheric ozone layer.

The UV spectral range is further divided in three sub-regions. UV-C includes the shortest wavelengths from 200 to 280 nm. It is an important factor in the photochemistry of the higher atmosphere but is entirely absorbed by atmospheric gases and does not reach the Earth's surface. Fractions of UV-B (280-315 nm) and UV-A (315-400 nm) do reach the ground and impact biological and chemical processes.

Some of these are related to human health: excessive exposure to UV may induce sunburns, skin ageing, skin cancer or eye diseases e.g. cataract. There is also increased evidence that UV radiation affects many ecosystems. UV is known to kill bacteria, phytoplankton, zooplankton and higher forms of life such as fish or amphibian eggs and larvae. It also negatively affects higher plants. Continued and aggravated ozone depletion would provoke a substantial increase in the UV radiation reaching the Earth and have important health, ecological and economic (e.g. crop yield, halieutic resources) consequences.

Regarding human health issues, it is fortunately easy to protect oneself from excessive UV exposure by using UV blocking creams, wearing a hat and sunglasses and avoiding exposure when the radiation is highest. These protective behaviours can be favoured by providing the citizen with better information on the levels of ambient UV. This necessitates improving our understanding of the factors determining the surface UV, devising techniques to quantify it and developing tools and means to convey the information to the public. An example is how the UV radiation should be quantified for a given effect. The shortest wavelengths are most effective in damaging human skin. UV-B is therefore the most important component but UV-A, because of its higher intensity, does contribute substantially to sunburns.

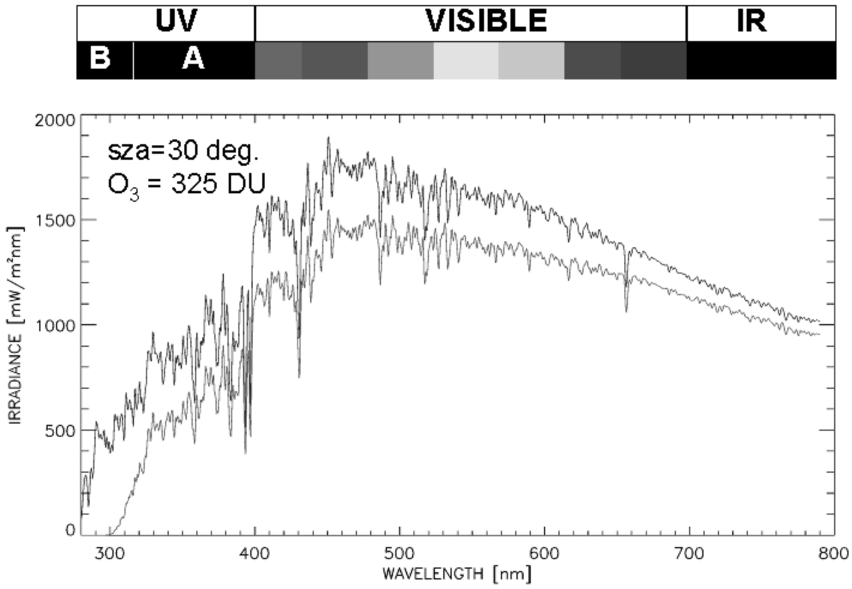

Figure 1: Solar irradiance at the top of the atmosphere (upper curve) and at the Earth's surface under typical conditions (lower curve).

To better quantify UV radiation for its erythemal effects, an action spectrum has been determined that attributes an efficiency factor to each wavelength. The "erythemal irradiance" is then obtained by summing over the whole UV wavelength range the weighted spectral irradiance. The CIE87 action spectrum (Commission Internationale de l'Eclairage – International Commission on Illumination) is widely used for this purpose. There are other action spectra associated with other effects such as skin cancer, DNA damage and effects on plants. The erythemal irradiance is an instantaneous value expressed in W/m^2.

To ease the use of the information by the public, WMO has also defined a UV index by mapping the erythemal irradiance on a simple scale ranging from 0 to 10 (in Europe). Many European meteorological institutes include this UV index in their weather bulletin or offer the information on their web sites. Data on the surface UV radiation can be obtained either by direct measurements or by radiative transfer modelling.

After a short review of the factors determining the surface UV radiation, the paper briefly reports on these two complementary ways of determining UV radiation.

FACTORS INFLUENCING SURFACE UV RADIATION

Solar zenith angle

The solar light intensity incident on the Earth surface directly depends on the solar zenith angle. This is why it varies with the time in the day (maximum at local solar noon) and with seasons.

Total Column Ozone

Atmospheric ozone is the permanent shield that protects the Earth surface from high levels of UV radiation. It is located throughout the atmosphere but mainly in the stratosphere where 90 to 95% of the total atmospheric ozone is found, hence the term ozone layer. This gas strongly absorbs the short wavelength solar radiation and considerably reduces the UV flux reaching the Earth surface.

With a typical total column value of 325 DU (Dobson Unit), the UV-B irradiance reaching the surface is reduced by a factor 12 with respect to the intensity incident on the top of the atmosphere. UV-C is reduced even more to the point that the amount reaching the surface is negligible while UV-A on the contrary is almost not affected.

Under Antarctic ozone hole conditions (ozone below 200 DU), the surface UV-B intensity can reach twice its “normal” value. Because of different atmospheric conditions (absence of a stable polar vortex, higher temperature) there is not an arctic ozone hole. However, the World Meteorological Organisation estimates that the UV radiation has increased by 3% per decade from 1979 to 1992 in northern mid-latitudes (WMO 1999). Besides the overall depletion resulting from anthropogenic substances, the amount of atmospheric ozone has natural geographical and seasonal variations that contribute to the variability of surface UV radiation. Ozone specifically attenuates the UV part of the solar light while it has almost no influence on visible light. When ozone is low the UV radiation can therefore by high while the perceived luminosity is normal as the human eye is not sensitive to UV radiation.

Clouds

When present, clouds are the major factor reducing the solar light intensity (including the UV) at the Earth surface. This reduction results from light scattering by the water droplets (or ice crystals), which sends back upwards a fraction of the incident light. A thick cloud can attenuate the surface UV intensity by more than 90%. Cloudiness is the most important factor contributing to the year-to-year variability in surface UV radiation and a trend in cloud cover would induce a trend in surface UV radiation.

Aerosols

Aerosols are particles suspended in the atmosphere; they are either of natural (e.g. dust) or anthropogenic origin. Just as the cloud water droplets, they reflect part of the incident solar light. Furthermore, some aerosols (e.g. black smoke) are also strong UV absorbers and large reductions in surface UV have been observed in areas affected by forest fires. In Europe, the atmospheric aerosol load is highest in regions such as the Po valley or the industrial area including Belgium-Netherlands-Luxerbourg and the Ruhr, where they reduce surface UV by 5 to 10%.

Altitude

Because the thickness of the atmosphere decreases, the surface light intensity (including UV) increases with altitude. This increase depends on the local atmospheric conditions but is of the order of 15% per km for erythemal (CIE87) radiation.

Surface reflectance

In the UV range, most terrestrial surfaces and water have a very low reflectance (a few percents). The exceptions are sand deserts (~ 15% reflectance) and snow. Pure fresh snow has a reflectance coefficient close to one. In this case the light incident on the surface is backscattered upwards instead of being absorbed. This leads to a substantial increase in UV exposure as experienced for instance during stays in sky resorts.

MEASURING SURFACE UV RADIATION

The basic way of documenting the surface UV radiation is to measure it with ground instruments. Many countries now maintain large networks of UV irradiance instruments, which are particularly well developed in Canada, USA, Japan, New Zealand and Europe. A number of instruments have also been deployed at high southern latitudes in South America and in the Antarctic.

The instruments fall into three main categories: broadband radiometers, multi-channel medium-spectral-resolution instruments and high-resolution spectrometers, in order of complexity and cost.

The broadband radiometers directly estimate the erythemal radiation. They are made of a single detector that receives the light through a filter matching the erythemal action spectrum. At the other end, the high-resolution (0.5-1 nm) spectrometers record the details of the spectral irradiance. The simple instruments allow building denser monitoring networks (low cost and maintenance) but they are subject to drifts in their sensitivity, which are difficult to detect and correct.

The spectral instruments on the other hand constitute the reference in term of accuracy. The detailed spectral information they provide is also crucial to understand the processes determining the surface UV intensity and to improve and validate the radiative transfer models. Important aspects to ensure the consistency and accuracy of the information are instrument inter-comparison, measurement protocols, quality procedures and archival of the data. The European Commission has strongly supported these activities within its Stratospheric Research Programme. The primary repository of UV data is the World Ozone and Ultraviolet Radiation Data Centre (WOUDC). A European database has also been established at the Finnish Meteorological Institute, with close links to WOUDC.

MAPPING SURFACE UV RADIATION USING SATELLITE DATA

The densest networks of instruments still are and will remain incapable of picturing the full geographical variability of surface UV radiation. Hence the interest of generating maps by radiative transfer modelling and using information on the influencing parameters, some of which is provided by Earth Observation satellites.

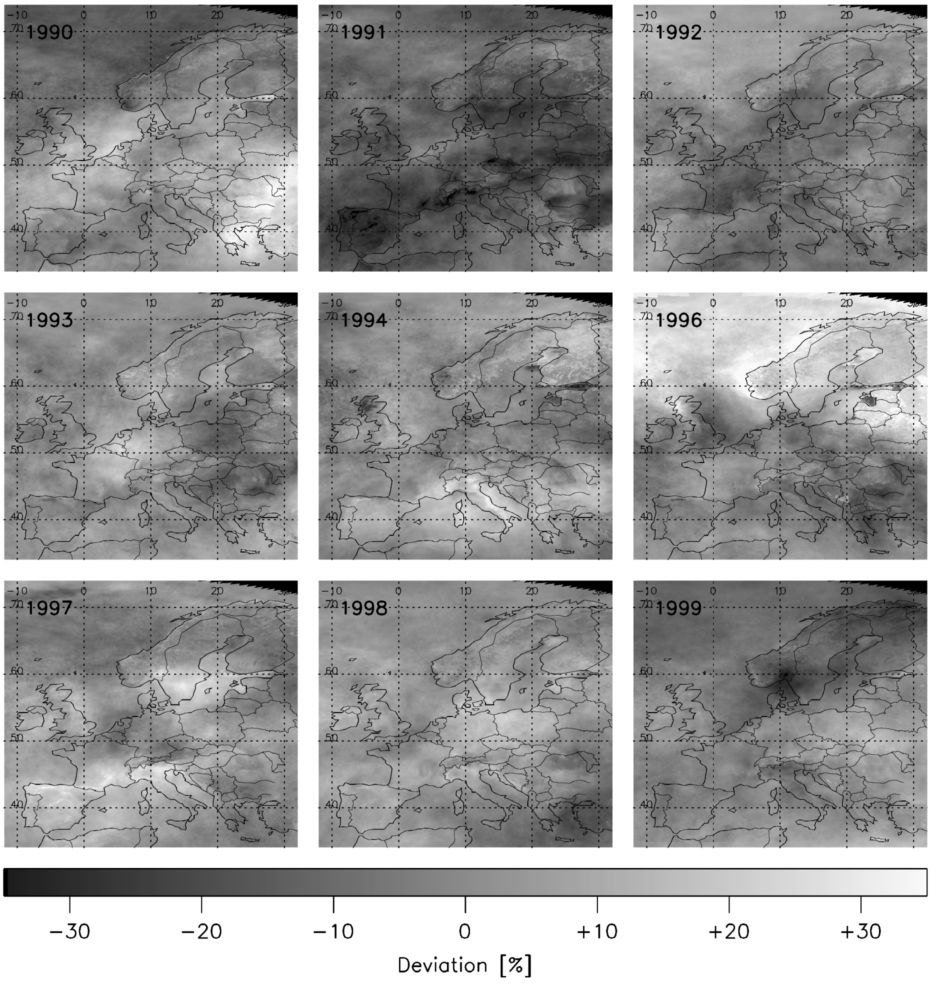

Figure 2: Relative deviation of the monthly averaged erythemal daily dose for March 1990 ‘91, ‘92, ‘93, ‘94, ‘96, ‘97, ‘98 and ‘99, with respect to the mean value for the nine years; 1995 is missing because of missing ozone data.

At the global scale, UV climatologies have been generated using data from the TOMS satellite instrument (Total Ozone Monitoring Spectrometer) (Eck *et al.* 1995; Lubin *et al.* 1998; Ziemke *et al.* 2000). Several European groups also have developed UV radiation mapping techniques that are applied on smaller areas but with a higher level of geographical details (Meerkötter *et al.* 1997, Slaper *et al.* 1998).

The European project MAUVE (Mapping UV by Europe, in the framework of the Environment and Climate Programme of DG Research) has largely contributed to this. For instance, the procedure developed at the Joint Research Centre makes use of total column ozone from satellites (TOMS and/or GOME, the Global Ozone Monitoring Experiment of the European Space Agency), cloud parameters derived from METEOSAT (the European meteorological satellite operated by EUMETSAT) and ground data on the other influencing parameters to generate European maps with a spatial resolution of 0.05 degree (Verdebout 2000).

As archived input data are available, it is possible to document the UV radiation in the past. JRC has undertaken to generate a European climatology covering the period from 1984 to present. A preliminary result is illustrated in Figure 2 which shows the year-to-year variability of the erythemal radiation in March during the nineties. One can see that there are considerable (± 35%) differences, which are explained both by variability of ozone and cloudiness. The high values in Greece in 1990, Italy in 1994 and Spain, Southern France and Italy in 1997 correspond to low cloudiness. The high UV in the north in 1996 on the contrary is entirely due to lower than average values of atmospheric ozone. These data are primarily used to support studies of UV radiation environmental impact.

It should be emphasized that these mapping techniques must be validated against the ground reference measurements. Indeed the model output is dependent on the validity of the input data and can only show the effects that have been explicitly taken into account.

NEAR REAL TIME INFORMATION AND FORECASTING

The most important input data to radiative transfer models are available in near-real time: for instance the METEOSAT images are distributed within half–hour of their acquisition and the space agencies have developed fast delivery products of total column ozone. The near-real time UV situation could therefore be estimated and made available to the public.

An increasing number of weather services are actually providing next-day forecasts of UV radiation intensity, usually in the form of the UV index. This is realised in a variety of ways. Some methods are based on radiative transfer modelling using forecasts of the ozone (as predicted by stratospheric circulation models) and of cloudiness (as part of the weather forecast). Others rely more on statistical analysis of long time series of ground UV measurements, combined with the weather forecast. The introduction of the UV index in the weather bulletins is certainly a good way of raising the awareness on the risks of excessive exposure to UV and helps citizens to plan their outdoor activities and to take protective measures.

CONCLUSIONS

There is today a wide range of complementary tools and techniques to document the surface UV radiation, ranging from measurements of various types to mapping by radiative transfer modelling. These means support scientific research on UV radiation and impact studies on the environment and human health but also provide information directly to the public, helping people to behave safely with respect to UV exposure.

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INTERNATIONAL AND EUROPEAN COMMUNITY CONTROLS ON METHYL BROMIDE & THE STATUS OF METHYL BROMIDE USE AND ALTERNATIVES IN THE EUROPEAN COMMUNITY

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ABSTRACT

Methyl bromide (MB) is a significant ozone depleting substance that was added to the Montreal Protocol in 1992. Regulation EC2037/00, adopted on 1 October 2000 in all 15 Member States (MSs) of the European Community (EC), is more stringent than agreements reached by the Parties to the Protocol on MB. Compared to the Protocol, regulations EC3093/94 and EC2037/00 required earlier and greater reductions in MB consumption, a cap on the amount of MB that can be used for quarantine and pre-shipment (QPS), minimum qualification requirements for fumigators, and a ban on the sale of MB in disposable cans. MB consumption is scheduled to be phased out in the EC on 1 January 2005 for the vast majority of its uses. Non-QPS consumption in the EC in 2001 was 7,702 tonnes which was placed on the market mainly in Spain, Italy, France, Belgium, Portugal, Greece and the United Kingdom. QPS consumption in the EC in 2001 was 812 tonnes. Many MSs in the EC have negligible or no further consumption of MB. The Parties to the Protocol are due to review in 2003 the developing country phase out schedule which bans MB consumption in 2015 except for QPS uses and potential critical use exemptions. A survey of MB uses and alternatives being used in MSs in the EC showed that in general alternatives were available but not yet in widespread use. This led to the general conclusion that a much greater effort was needed in technology transfer and awareness raising of alternatives to MB with some continued effort on research and registration of existing chemicals for new uses.

Keywords: methyl bromide, Montreal Protocol, control measures, alternatives, European Community, survey of alternatives

INTRODUCTION

The Montreal Protocol on Substances that Deplete the Ozone Layer (referred to in this paper as ‘the Protocol’) has 170 signatory Parties and is now widely acclaimed 15 years after its introduction as one of the most successful international environmental treaties. The Protocol establishes the phase out schedules to eliminate the [2]consumption of the most harmful ozone depleting substances (ODSs) including MB(MB) (Anon 2000a). MB, first listed by the Protocol as an ODS in 1992, has an ozone depletion potential (ODP) of [3]0.6. This was lowered by the Protocol’s Science Assessment Panel (Anon 1999) to 0.4 based on more recent information. However, 0.4 is still considered a significant ODP necessitating the phase out of MB.

The first section in this paper discusses Protocol agreements on MB that affect developed and developing countries, and the EC legislation adopted subsequently that restricts the future use of MB, and the consumption of MB in the EC. The last section discusses the results of a survey of key MSs on MB uses and alternatives in order to determine research priorities, the extent of technology transfer and hence the likelihood of compliance with the Protocol and national legislation on MB.

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[2] *‘Consumption’ is defined as ‘(Production + Imports) – Exports’ which in effect controls the reduced amount of MB that can be placed on the market each year, relative to its consumption in each country in 1991.*

[3] *All ODPs are relative to CFC-11 which has an ozone depletion of 1.0. Except for mainly medical uses of CFCs where alternatives have yet to be developed, the vast majority of CFC production was banned in developed countries in 1994.*

CONTROLS ON METHYL BROMIDE

Montreal Protocol

Developed countries

The Parties to the Protocol agreed in 1994 to a MB phase-out schedule for countries whose economy is in transition (CEITs) and developed countries consisting of a 25% reduction in consumption on 1 January 1999 relative to 1991 levels, a 50% reduction on 1 January 2001, a 70% reduction on 1 January 2003 and a total phase out of consumption on 1 January 2005 with possible critical use exemptions. Developed countries are permitted to produce 10-15% of their MB 1991 production volume to meet the Basic Domestic Needs (BDN) of developing countries, the precise amount depending on the stage of developing country phase out.

The amount of MB consumed for quarantine and pre-shipment [4](QPS) applications was excluded from control as the Parties in 1994 considered, *inter alia*, MB important for rapid and effective insect disinfestation of a small but highly-valued proportion of food entering national markets. The Parties also wished to avoid any new non-tariff trade barriers as they considered trade was likely to increase in developing countries resulting in greater MB use in these countries in the absence of viable alternatives for QPS treatments.

Developing countries

The Parties to the Protocol typically allow developing countries 10 years longer than developed countries to comply with ODS phase out schedules in recognition of their generally inadequate infrastructural and financial resources. The Parties therefore agreed in 1994 to a MB phase-out schedule for developing countries consisting of a freeze in consumption on 1 January 2002 relative to their average consumption from 1995 to 1998, a 20% reduction on 1 January 2005 and a total phase out of consumption on 1 January 2015 with possible critical use exemptions. The amount of MB consumed in QPS applications was excluded from control.

The Parties also agreed to review at their annual meeting in 2003 the phase out schedule for developing countries with a view to accelerating the phase out schedule in developing countries in the light of progress on the implementation of alternatives. To assist developing countries with the implementation of alternatives, developed countries have to date contributed more than $50 million from the Protocol's Multi-Lateral Fund. The Protocol's Technology and Economic Assessment Panel (TEAP) is scheduled to produce a report in April 2002 summarising developing country progress on the implementation of alternatives which will provide a useful basis for the Parties' 2003 review of the developing country phase out schedule.

Some developing countries have unofficially accelerated their phase out schedule to avoid further dependency on MB and potential consumer boycotts in developed countries of MB-treated commodities. For example, Morocco has several projects that will introduce alternatives for major crops, and plans to reduce MB imports/consumption from 1,600 tonnes in 1998 to 275 tonnes in 2006 (Miller 2001). Turkey will introduce alternatives for tomato, cucumber, cut flowers and dried fruit, and has made a commitment to reduce MB imports/consumption from 840 tonnes in 1997 to 34 tonnes in 2006.

European Community

Similar to other Parties to the Protocol, the EC reflected in its own legislation agreements achieved under the Protocol and, moreover, incorporated elements more strict than those in the Protocol where

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[4] *The* Seventh Meeting of the Parties *decided in* Dec VII/5 *that Quarantine Applications are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where 'official control' is that performed by, or authorised by, a national plant, animal, environmental protection or health authority; and 'quarantine pests' are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled; The* Eleventh Meeting of the Parties *decided in* Dec. XI/12 *that Pre-shipment Applications are those non-quarantine applications applied within 21 days prior to export to meet the official requirements of the importing country or existing official requirements of the exporting country. 'Official requirements' are those which are performed by, or authorised by, a national plant, animal, environmental, health or stored product authority.*

these were feasible. Regulation EC2037/00 on Substances that Deplete the Ozone Layer entered into force on 1 October 2000 in all fifteen MSs in the European Community (EC) more than two years after the original European Commission draft had been discussed and negotiated by industry, the European Council of Ministers and the European Parliament (Anon 2000b). Unlike a Directive whose parts can be transposed into MS legislation, a Regulation is mandatory and must be implemented in its entirety by each MS from the date of its entry into force.

Articles 3 (production) and 4 (placing on the market) contain the most information pertaining to MB in EC2037/00. In general, EC2037/00 mandates larger percentage reductions in MB consumption in the relevant years for non-QPS uses compared to the Protocol but the same final phase-out date as the Protocol. Importantly, through the implementation of EC2037/00, the EC became the first Party to place a limit on the amount of MB that could be used specifically for QPS purposes. The Commission, in consultation with MSs, must also encourage the development and use of alternatives to MB as soon as possible. An international conference such as this one held in Sevilla that summarises the research and implementation of alternatives to MB is one example of meeting the requirements of this aspect of EC2037/00.

In other articles of the Regulation applicable to MB, Article 16 bans MB placed on the EC market in disposable containers. Article 17 requires MSs to have in place qualification requirements for fumigators and to define the minimum qualification requirements for personnel involved in MB installations and operations. All precautionary measures practicable must be taken to prevent and minimise leakages of MB from fumigation installations and operations in which MB is used. Whenever MB is used in soil fumigation, the use of virtually impermeable films for a sufficient time, or other techniques ensuring at least the same level of environmental protection, shall be mandatory.

Non-QPS consumption

Most non-QPS MB is used for soil disinfestation, with smaller volumes used, for example, in the treatment of flour mills, for disinfestation of durable commodities such as rice and cocoa, and for disinfestation of structures such as insect-infested churches.

Relative to 1991 consumption in the EC, the previous regulation EC3093/94 required a 25% reduction in 1998, one year earlier than required under the Protocol (Anon 1994). EC2037/00 required a 60% reduction on 1 January 2001, 10% more than required under the Protocol. A 75% reduction will be required on 1 January 2003, 5% more than required under the Protocol. No further consumption is permitted after 31 December 2004. Any stocks of MB remaining after this date in the EC could be used only until 31 December 2005 whereas under the Protocol they could be used for a longer period of time.

In the calendar year 2001, the quantity of MB licenced by the Commission to be placed on the EC market for non-QPS purposes was 6,362 metric tonnes. The amount requested to be imported was about 17% below the cap in EC2037/00. Of the 6,362 metric tonnes, more than 92% was imported by three of the six MB importers and sold in Spain, Italy, France, Belgium, Greece, Portugal and the UK. Denmark, Finland, Sweden, The Netherlands and Germany no longer use MB for soil disinfestation.

In order to encourage year-long MB availability in 2001 for non-QPS uses, 95% of the quota for each importer was licensed by the Commission for imports from 1 January, 3.75% from 1 July and the remainder from 1 October. Annual import quotas are based on relative historical, importer market-share and approved annually by the Commission and MSs under Article 18 of EC2037/00. Atofina (F) is the only EC producer and was licensed to produce or import up to 1,370 tonnes of MB for non-QPS uses in 2001.

QPS consumption

EC2037/00 mandated a freeze on the use of MB for QPS from 1 January 2001 based on the three-year average of the amount of MB imported and produced from 1996 to 1998 inclusive. In an emergency, where unexpected outbreaks of particular pests or diseases so require, the Commission, at the request of the competent authority of a MS, may authorise the temporary use of MB. Such authorisation for 120 days or less and cannot exceed 20 tonnes. Commencing in 2002, MSs must report to the Commission on the quantities of MB authorised for QPS in their territory in the previous year, the purposes for which it was used, and the progress in evaluating and using alternatives for

QPS. EC2037/00 aims to ensure that MB consumption for QPS is reduced over time as alternatives are developed.

In 2001, EC2037/00 permitted 487 ODP tonnes, equivalent to 812 metric tonnes, to be placed on the EC market for QPS purposes. Based on a Commission survey in 2001, there are no QPS uses in Denmark, Finland and Sweden; and in Austria relatively small quantities of MB are used for emergency QPS applications.

In order to encourage year-long MB availability in 2001 for QPS uses, 90% of the quota for each importer was licensed by the Commission for imports from 1 January and the remainder allocated from 1 October. Annual import quotas are based on relative historical, importer market-share and approved annually by the Commission and MSs under Article 18 of EC2037/00.

Critical uses

For any use of MB that remains without an alternative on 1 January 2005, and in response to any proposal made by a MS, the European Commission together with MSs must determine annually quantities of MB permitted for critical uses, and the users who may make use of the critical use exemption. The Parties to the Protocol must then approve the EC volume of MB requested for critical uses. In determining critical uses, the Commission and MSs must apply the Protocol criteria contained within *Decision IX/6* 'Critical Use Exemptions for Methyl Bromide' (Anon 2000b) and any other relevant criteria agreed by the Parties. The Production or importation of MB can only be permitted once it has been ascertained that supplies of MB (reclaimed, recycled), or adequate alternatives, are not available from any of the MSs.

EC SURVEY ON THE IMPLEMENTATION OF ALTERNATIVES

A survey was conducted by the European Commission on the use by sector of MB for non-QPS and QPS applications in the MSs where MB is currently consumed, namely Spain, Italy, Greece, France, Belgium, Portugal and the United Kingdom. The Form requested information on the availability of alternatives in the next four years. The Survey Form has not yet been returned by Belgium. The Survey Form received from Greece is pending clarification. The results below were therefore obtained from Survey Forms returned by Spain, France, Italy, Portugal and the United Kingdom.

The survey returned by Spain showed mainly that only 14% of non-QPS uses have no potential alternative to MB in 2000, although more than 86% of non-QPS consumption is expected to have an alternative by the end of 2004. Only 30% of the cut-flower growers were using an alternative in 2000. Spain was uncertain if strawberry nurseries and cut-flower growers would be using alternatives by the end of 2004. There were no reported alternatives for QPS uses.

Preliminary information from France reported reductions in the use of MB to about 750 tonnes for non-QPS uses. The reductions were due to officail reduction schedules, a ban on the use of MB in some crops where bromide residues are of concern such as lettuce, and a growing interest in the use of substrates (Fritsch 2002).

The survey returned by Italy showed that, of the 4,000 tonnes of MB consumed in 2000, only 4% of non-QPS uses did not have potential alternative, although more than 96% of non-QPS consumption is expected to be replaced by an alternative by the end of 2004 or 2005. About 30% of the total end-users were using an alternative in 2000. Italy reported alternatives to MB were being used or were under consideration for QPS uses to control a wide range of pest species.

Portugal reported approximately 220 tonnes of MB consumed for non-QPS uses in 2000, most of it used in the production of strawberries (45%) and cut-flowers (28%). Portugal expected that 90% of its end-users would be using an alternative to MB by the end of 2005. Portugal reported a 38% decrease in sales of MB in 2000 compared to 1999, and a comparable increase in nematocide sales. Portugal reported 2 tonnes of MB for QPS uses on chestnut and almond exports. Heat treatment was under consideration for chestnuts. A treatment for almonds was not known.

The survey returned by the United Kingdom showed mainly that only 3% of users with a potential alternative were using an alternative to MB in 2000, although more than 90% of users are expected to be using an alternative by the end of 2005. Lack of registration is impeding the use of alternatives for food facilities and flour mills. By the end of 2005, the United Kingdom was uncertain if an alternative would be in place for soil disinfestation for cut flowers.

Belgium's MB consumption is reported to have continually declined since 1991 due to interest in production using substrates and other factors (Pauwels 2002). Consumption for non-QPS uses in 2000 was 102 tonnes and is estimated to be 33 tonnes for 2001, compared to 1991 when consumption was 312 tonnes.

Based on these survey responses, it would seem that further research is needed in some areas but the majority of the effort needs to be on awareness raising of alternatives (see Miller 2002) and technology transfer. Some MSs do not appear to have undertaken an assessment of the quantity of MB used and alternatives that have replaced existing uses of MB making an assessment of future compliance with EC2037/00 on MB control schedules difficult to predict. There is also an urgent requirement for registration of existing chemical materials for new uses to allow their use in the EC as alternatives to MB.

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NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE FOR SOIL TREATMENT IN STRAWBERRY PRODUCTION

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ABSTRACT

Modern strawberry varieties are highly dependent on soil disinfestation to maximise yields and, in regions of the world where productivity is paramount, this is making it difficult to find non-fumigant alternatives to methyl bromide. Consumer concern over pesticide residues and their effect on the environment and human health are forcing industries to consider more sustainable, non-chemical methods for food production. This paper analyses the importance of soil disinfestation for strawberries and suggests a number of non-chemical options which should be considered for future production in strawberry industries worldwide.

Keywords: non-chemical, strawberry, substrates, solarisation, varietal resistance, organic amendments, biofumigation, PGPR's, biocontrol

INTRODUCTION

The listing of MB for phase out, whilst initially difficult for the strawberry industry, has forced researchers to develop a greater understanding of the dynamics and ways to improve the performance of both chemical and non-chemical treatments for soil disinfestation. This has led to a number of options which either replace methyl bromide (MB) or avoid the need for MB. The use of non-chemical methods such as solarisation, steaming, biofumigation, organic amendments and IPM are now used successfully for strawberry production in specific regions throughout the world and should be considered for use instead of MB where climatic conditions, crop rotation and productivity constraints permit their use.

Besides the pressures from phase out of MB, market demand for organic or low chemical inputs into food production is also forcing industries to consider alternative, more sustainable methods of food production. Evidence for this is the increase in retail sales of organically produced goods which have grown by 20 % per year in the US reaching $7 billion in 2000, and 40% per year in the United Kingdom. At present, however, only a small percentage of strawberries, 1% in California (Bull & Koike 2001) are produced organically.

Table 1: Non-chemical methods in the strawberry fruit and runner industries which are alternatives to methyl bromide fumigation.

	Alternative for fruit production	Alternatives for nursery runners
In-kind non chemical alternatives to MB	• Solarisation • Steaming?	• Steaming? • Solarisation??
Methods which avoid the need for disinfestation	• Resistant varieties • Soilless substrates	• Soilless substrates (Plug plants)
Other 'non chemical' alternatives to methyl bromide	• Crop rotation • IPM • Organic amendments Biofumigation • Biological control • PGPR's, myxobacteria • Electromagnetic radiation	• Virgin soil, IPM and weed cultivation

	Alternative for fruit production	Alternatives for nursery runners
	• Coloured plastic films, mulches, propane burners for weed control	

WHAT ARE THE MAIN NON-CHEMICAL OPTIONS TO METHYL BROMIDE ?

Alternatives which act as in-kind replacements to MB, must have a similar or better ability than MB to provide effective eradication of soilborne propagules of weeds, pests and diseases. These alternatives generally create a partial biological vacuum and alter the nutrient status of soils. They are mainly used in regions where maximum attainable yields are sought. Alternatively, integrated systems which create an environment which is suppressive to pathogen attack or weed seed germination are generally based on methods which manipulate existing or increase microbial diversity in soils. These are more suitable to production regions where pesticide and environmental concerns dominate production rather than maximum attainable yields. The major non-chemical options are shown in Table 1.

Strawberry nurseries

In the strawberry nursery runner industry the need for complete elimination of diseases (ie. eradication of pathogens) and weeds, means that in the short term, large scale production is likely to rely on chemical disinfestation or soilless production systems ("plug plants"). The physiological requirement for chilling prevents solarisation being suitable in nurseries because of the cool climatic zones where nurseries are located worldwide. Other possible non-chemical options are steaming for small scale areas or runner production on virgin soils (previously non-cropped soil) combined with a range of integrated pest management treatments and manual or chemical weed cultivation.

<u>Plug plants:</u> Strawberry plug plants offer the best opportunity for the strawberry runner industry to reduce its reliance on chemical fumigation. Plugs have the advantage that they can be 'certified' disease free and yield good quality fruit, 2 to 3 weeks earlier than bare rooted runners produced in soil (Sances 2001). At present, plugs generally only compete for early or short season markets. Although approx. $3 million plug plants were produced in California in 2001, future markets will be restricted by high production costs compared to a standard runner plant (US$ 0.15 - 0.17 cf. $0.08 approximately), the extra handling and transport costs and the present shorter season production of some varieties (Sances *pers. com*. 2002).

Strawberry fruit production

<u>Solarisation and steaming:</u> As heat can directly kill pathogens and weed seeds, solarisation in hot climatic regions offers an excellent alternative for soil disinfestation for strawberry fruit production providing periods of hot climatic conditions suit the crop rotation. Solarisation alone or combined with IPM (organic amendments) is used as an alternative to MB in several arid regions, eg. Jordan, but has varied in effectiveness in other regions eg. Huelva, Spain (Batchelor 2000; Lopez-Aranda *et al*. 2000; Romero 2000). Solarisation is cheaper to apply than MB (up to 80%) and provided it is used with a suitable crop rotation can produce acceptable yields (Batchelor 2000). At present steaming is difficult for strawberries as cost, time requirements and access to power, fuel and water prevents open field use on a large scale. Recent advances in mobile steam machines (Celli Pty Ltd, Italy) may improve the adoption of this technique.

<u>Resistant varieties:</u> In many developed countries overproduction during traditional strawberry seasons and narrow profit margins have forced breeders and industries to select and grow high-yield, long season strawberry varieties. These varieties are often particularly sensitive to biological and nutrient changes in soil, pests and disease and competition from weeds. For this reason, most current strawberry varieties respond well to soil disinfestation achieving yields over 40% greater than strawberries grown on non-disinfested soils (Hancock *et al.* 2001; Shaw and Larson 2001).

Development of resistant varieties as an alternative to MB has been difficult because of the high levels of resistance required for the wide range of pathogens that affect strawberries. Also, the continual turnover of commercial varieties has made it difficult for breeders to maintain robust resistance to many of these pathogens. For instance, recent studies in the US have shown vastly different levels of resistance to *Phytophthora* spp and *Pythium* spp. in existing and newly released varieties (Browne *et al.* 2001) and in organic production (Bull & Koike 2001). The US strawberry cultivars Aromas, Camarosa and Pacific generally offered much better resistance to *Phytophthora* than Diamante, Gaviota and Pajaro; and Selva, Aromas and Carlsbad have shown better resistance to *Pythium* than Camarosa and Chandler (Martin 2000).

Soilless culture/hydroponics*:* As market pressures against pesticides increase, more and more strawberries will be produced in substrates under hydroponics. Currently, only a small proportion (<3%) of the world's strawberries are produced this way and normally only for crops that are grown to meet early, late or specific niche markets that fetch high prices. Holland, Japan, Italy, New Zealand, UK and China are some of the key producers of hydroponic strawberries. Scotland produce over 28 ha of strawberries in substrate systems, which is over 7% of their total production (Batchelor 2000). These substrate systems produce 46% more fruit per year than crops in MB treated soil, because growers can crop twice per year. Although the substrate systems cost approximately 60% more than production in soil with MB, the substrate system is more profitable from the third year onwards. Reduction in initial set up costs for substrate systems will increase their adoption as an alternative to MB worldwide. In England this has been achieved by using rockwool grow bags grown on plastic mulched beds on the ground in removable Spanish tunnels (Scott Raffle *pers comm.* 2002).

Integrated Pest Management and other methods*:* Between 20 to 30% of the world's strawberries are grown without MB fumigation using a range of IPM techniques. The key components are clean mother and runner stock, good crop rotation, biofumigation, fungicide dips, herbicides and strategic use of organic amendments (Batchelor 2000). Even short rotations are beneficial. One year rotations out of strawberry production increased yields of strawberries 18 to 44% in California (Duniway 2000). Biofumigant crops have been adopted in rotations in Australia, Uruguay, Poland and many other countries, but generally do not act as direct replacements to soil disinfestation. Organic amendments, which produce volatiles (ammonia, isothiocyanates, nitrous acid), biological control agents and manipulation of beneficial organisms that colonise the rhizosphere (PGPR's, myxobacteria) offer potential but to date have failed to give consistent disease protection and yield benefits for strawberries (Duniway *et al.* 2000; Martin 2000; Lazarovits *et al.* 2001). Electromagnetic waves have been unsuccessful in Spain (Lopez-Aranda *et al.* 2000)

Generally crop production costs with IPM are less than that with MB. Yields with IPM can be equivalent to MB in areas where cannisters are used, but lower when MB is injected into soils. Cannisters are banned in the European Community. Typical good yields in Australia with IPM and MB are 50t/ha and 70t/ha respectively. Although yields in England are lower, a similar trend is observed (approx. 20t/ha cf. 30t/ha for MB). In some countries successful IFP strawberry production guidelines have been introduced to lift production. In Poland yields for export processed and frozen strawberries have increased from 4-5t/ha to 12t/ha (Batchelor *pers com.* 2001). This system relies on a three year rotation, cropping only after cereals or mustards, nutrient analyses, animal manure, *Tagetes* for nematode control and minimal pesticide use.

WHY IS SOIL DISINFESTATION IMPORTANT FOR STRAWBERRY PRODUCTION?

Strawberries respond better than most crops to soil disinfestation with yields increased over 35% in temperate regions of the world with long production seasons eg. California, Spain, temperate Australia. In the last few years, studies in Australia have identified that strawberries respond well to the destabilised biological and nutrient equilibrium created by soil disinfestants, mainly chemical fumigants, but the same would apply to steam and solarisation (Figure 1). Studies (Hansen 1990; Porter *et al.* 2000) have consistently shown that soil fumigation dramatically increases ammonium nitrogen and many other nutrients in soil and decreases microbial populations in the rhizosphere (Donohoe *et al.* 2001). Higher levels of ammonium, together with rapid recolonization by beneficial gram negative bacteria, may contribute to the increased growth response (IGR) observed in strawberries. In view of the above effects, recent studies in Australia have concentrated on finding integrated crop management systems for strawberry fruit production with and without chemical fumigation, which produce the same pathogen and weed control as MB and a similar IGR.

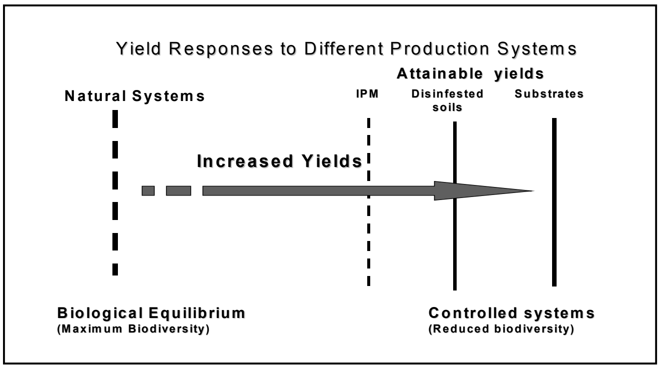

Figure 1: Relationship between plant production systems, crop yields and biodiversity

Treatments consisted of factorial combinations of; a slow release NH_4^+ fertiliser; a biocidal pre-plant runner dip and soil amendment (BCDMH); pre-emergent herbicides (napropamide and metolachlor) in either MB fumigation or non-fumigated soils. Overall, fumigation with MB had the largest effect of all treatments increasing strawberry yields by 25%. Herbicides had no phytotoxic effect on strawberries, but did not increase yields. Similarly, fertiliser application did not affect strawberry yield. In contrast, BCDMH increased strawberry yields by 10%, which was due to the treatment reducing the incidence of crown rot caused by *Phytophthora cactorum* by 66%.

CONCLUSION- IS THE STRAWBERRY FRUIT INDUSTRY READY TO ACCEPT RESPONSIBILITY FOR SOIL SUSTAINABILITY?

The majority of strawberries grown worldwide are still grown on soils fumigated with MB. Since 1999, shifts in the use of products with lower concentrations of MB (ie. MB/chloropicrin (Pic) 50:50 and 30:70) and a switch to other chemical fumigants (Telone/PIC mixtures) have enabled countries to meet the mandatory 50% reduction in consumption of MB in 2001 under the Montreal Protocol. These strategies may no longer be sufficient to disinfest soils into the future as supplies of MB dry up and pressures on chemical use increases. Consideration should be given to non-chemical production systems and integration of non-chemical and chemical treatments where possible, especially methods which reduce the dosages of chemicals applied (eg. using virtually impermeable film) or coloured films to reduce weeds.

In the short term, the strawberry industry has three choices: It can switch to the next best fumigant alternative, develop alternative integrated crop management systems or invest in the development of production systems which enable soil and environmental sustainability. The latter requires a greater understanding of the chemical and biological factors which maximise crop yield, greater crop rotation, the development of varieties with greater resistance to disease and may mean a change in production systems and perhaps production regions. Is the industry ready and if not, can it afford to wait?

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CHEMICAL ALTERNATIVES TO METHYL BROMIDE FOR SOIL TREATMENT PARTICULARLY IN STRAWBERRY PRODUCTION

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ABSTRACT

None of the chemical alternatives currently registered and available in the U.S.A. has the full spectrum of activity and versatility that methyl bromide (MB) has as a pre-plant soil fumigant. Chloropicrin and/or 1,3-dichloropropene (Telone) can give significant control of many plant pathogens in soil and yield stimulation in strawberry. Methyl isothiocyanate generators such as metam sodium and dazomet have broad biocidal activity in soil, but are more difficult to apply effectively. In most soil applications for strawberry, the available alternatives are likely to be used in combinations, either as mixtures (e.g., 1,3-dichloropropene and chloropicrin) or sequentially in time (e.g., chloropicrin followed by metam sodium). They may also be supplemented with other more specific pesticides and cultural controls. Among the known alternatives not yet available, methyl iodide and propargyl bromide probably have activity that most closely parallels that of MB in soil. However, all of the chemical alternatives to MB for strawberry production will be subject to continuing review and more regulation.

Keywords: Chloropicrin, dazomet, 1,3-dichloropropene, metam sodium, methyl iodide, methyl isothiocyanate, propargyl bromide.

INTRODUCTION

Strawberry cultivation in California has evolved over the last 40 years into a highly productive system that relies heavily on soil fumigation with methyl bromide (MB) (Wilhelm & Paulus 1980). While a variety of crop production systems have been heavy users of MB (Ristaino & Thomas 1990), in recent years there has been more research on the alternatives to MB for strawberry than for any other crop production system (e.g., Porter *et al.* 1999). Since about 1965, well over 90% of the land used for strawberry production in California has been fumigated with mixtures of MB and chloropicrin before each crop is planted, both for fruit production and for runner plant production in nurseries (Wilhelm & Paulus 1980). The resulting high level of control of soilborne pathogens has allowed breeders to concentrate on developing varieties with very high yield potential and berry quality, and has allowed horticulturists to further optimize California s annual production system to obtain high and consistent yields (Wilhelm & Paulus 1980, Yuen *et al.* 1991). California now produces about 80% of the U.S. fresh market strawberries and about 20% of the total worldwide. In 1999, strawberries were produced on over 9,700 ha in California and had a farm gate value over US$800 million. In addition, there is a large nursery industry producing several hundred million runner plants each year, many of which are exported. Soil fumigation remains central to this production system. A recent summary analysis of 45 studies, where strawberry yields in California were compared with and without standard MB-chloropicrin fumigation of soil, showed that on average fumigation increased yield 94% (Shaw & Larson 1999).

Soil fumigation was first developed for strawberries in California because of a pressing need to control Verticillium wilt and weeds (Wilhelm & Paulus 1980). As was the case in other cropping systems, the advantages of soil fumigation with MB and chloropicrin mixtures for control of other soilborne pathogens of strawberry, including important *Phytophthora* species and nematodes, soon became apparent (Ristaino & Thomas 1991; Wilhelm & Paulus 1980). In addition, soil fumigation generally increases root health, growth, and berry yields in strawberry even when known, major pathogens are not present in soil (Wilhelm & Paulus 1980; Yuen *et al.* 1991). Whatever the underlying mechanisms, the lack of economic yields in strawberry without fumigation is in part a replant problem. For example, when land with no history of strawberry culture was first planted with strawberry for several consecutive years with and without annual fumigation of the same plots, the beneficial effects of fumigation on yield increased with years of repeated strawberry (Duniway, unpublished). Unfortunately, because of high land costs and the need for high potential returns each year, many strawberry growers in California are forced to replant strawberries in the same fields yearly without rotation.

CHEMICAL ALTERNATIVES TO METHYL BROMIDE

Chemical alternatives that are available in the U.S.A. and that have known broad-spectrum activities in soil are chloropicrin, 1,3-dichloropropene (1,3-D), and the methyl isothiocyanate (MITC) generators metam sodium and dazomet. Each may be used individually, but they are more likely to be used as mixtures (e.g., 1,3-D and chloropicrin) or in sequential applications (e.g., chloropicrin followed by metam sodium). Fortunately, improved methods of application for these chemicals to soil are evolving at this time. While the available alternatives do not cause depletion of stratospheric ozone, relative to MB, they all have limitations in activity and/or versatility as soil fumigants. Among the chemical alternatives that are not registered and therefore require further development, methyl iodide and propargyl bromide stand out for having good information on their level and broad spectrum of activity in soil. They are also not sufficiently stable in the atmosphere to cause significant stratospheric ozone depletion. The many other chemical alternatives proposed have either insufficient activity or feasibility for soil fumigation, or too little is known about them to suggest they might actually become useful and registered replacements for MB in the near future.

Chloropicrin was first used for strawberry culture in California to control Verticillium wilt and it has strong fungicidal activities in soil (Wilhelm & Paulus 1980). Chloropicrin is less nematicidal than MB or 1,3-D and is less active on dormant weeds and seeds in soil. The early use of chloropicrin as a soil fumigant in strawberry production was rapidly replaced by mixtures of chloropicrin with MB (e.g., 67/33, 57/43%) because such mixtures have a broader spectrum of activity (including weeds and nematodes) and a synergistic activity for control of *Verticillium dahliae* in soil (Wilhelm & Paulus 1980).

More recent trials of chloropicrin as a stand-alone soil fumigant for strawberry production in California show that it is still effective. For example, in large replicated field experiments carried out near Watsonville, broadcast fumigation with chloropicrin at 336 kg/ha gave 94-96% of the strawberry yields obtained with a standard mixture of MB and chloropicrin (Duniway *et al.* 1997). While chloropicrin can also be effective in bed applications which require less material, results for strawberry production at a coastal site near Watsonville have been variable. For example, shank applications of chloropicrin to 2-row beds gave 90, 109, 117 and 77% of the yields obtained with MB and chloropicrin in the years 1995-98, respectively (Duniway *et al.* 1998). All of the bed fumigation treatments in these experiments gave a high and equivalent level of Verticillium wilt control and other factors are likely to have contributed to the year-to-year variation in the relative effectiveness of chloropicrin.

A survey of earlier fumigation trials for strawberry production in California suggests that soil fumigation with chloropicrin alone in place of MB mixed with chloropicrin will result in an average yield loss of 9.6% (Shaw & Larson 1999). The same survey suggests that high rates of chloropicrin are more effective and that the performance of chloropicrin may decline with consecutive years of use on the same ground for strawberries. While the latter result is doubtful, we clearly need better data on the minimum rates of chloropicrin needed for effective soil treatment, especially where major pathogens are present in soil. Although chloropicrin is registered and available now for use as a soil fumigant in California, there is resistance by regulators in some counties to the use of the high rates we know to be most effective. In addition, methods to apply chloropicrin as an emulsion in water through drip irrigation systems are under development (e.g. Trout & Ajwa 1999). While chloropicrin has considerable utility as a stand-alone fumigant in soil, it is more likely to be used in mixtures with 1,3-D or in sequential applications with metam sodium (e.g. Duniway et al. 1997, 1998, Trout & Ajwa 1999).

1,3-Dichloropropene (1,3-D) was initially developed as a nematicide, but its known spectrum of activity includes certain plant pathogenic fungi and bacteria. 1,3-D is available in the U.S.A. as a fumigant under the brand name Telone (Trademark of Dow AgroSciences LLC), either as a stand-alone fumigant (Telone II, 94% 1,3-D) or in mixtures with 17 or 35% chloropicrin (Telone C-17 and Telone C-35, respectively). As distributed in the U.S., 1,3-D is a mixture of *cis* and *trans* isomers with the *cis* isomer being the more biologically active. While 1,3-D is volatile and somewhat mobile in the soil as a gas, it is less volatile and mobile than MB. It is also not likely to be used as a stand-alone soil fumigant in strawberry production. For example, in one large experiment on strawberry a mixture of 70% Telone II and 30% chloropicrin gave significantly higher yields than did Telone II alone, and the mixture approximately doubled yields relative to nonfumigated soil in a manner similar to standard fumigation with MB and chloropicrin (Duniway *et al.* 1997).

While a survey of earlier fumigation trials for strawberry production in California suggests that soil fumigation with Telone mixed with chloropicrin is no better than fumigation with chloropicrin alone (Shaw & Larson 1999), more recent experiments with Telone C-35 have shown it to be a highly effective fumigant for strawberry production in California. For example, shank applications to preformed beds with Telone C-35 at 473 kg/ha (treated bed area) often gave yields equivalent to those obtained with MB/chloropicrin (Duniway *et al.* 1998). Perhaps more important is the recent evolution of methods to emulsify Telone C-35 in water for delivery into preformed beds through drip irrigation systems under plastic mulch (Duniway *et al.* 1998, Trout & Ajwa 1999). Numerous experiments and grower trials have now been carried out with drip and/or shank applied Telone C-35 for strawberry and it is likely to become one of the preferred alternatives to MB/chloropicrin for strawberry production in California. Furthermore, in part because of its strong nematicidal activity, Telone may also become an important component of soil fumigation practices for nursery production of runner strawberry plants in California.

Methyl isothiocyanate (MITC) is the primary active agent of metam sodium in soil and is a broad spectrum fumigant. While metam sodium is registered, available to growers, and has been used widely, it has a reputation of being unreliable if not used carefully. Unfortunately, current application practices rarely achieve an optimum distribution or the ideal conditions of soil temperature and moisture for MITC to kill all stages of plant pests and pathogens. Metam sodium and its active derivatives are not very mobile in soil and the product must be delivered to the volumes of soil targeted for treatment either by mechanical placement or by water infiltration. Recent studies have generally shown that metam sodium applied into preformed beds through drip lines under plastic mulch at 200-300 L/ha of treated area gives about half the yield increase induced by standard fumigation with MB and chloropicrin (Shaw & Larson 1999, Trout & Ajwa 1999). Unfortunately, metam sodium probably reacts with chloropicrin and 1,3-D in aqueous solutions and simultaneous or combined applications of metam sodium with these other fumigants have not been very successful (Trout & Ajwa 1999). Sequential applications separated by several days in time, however, can be effective.

MITC can also be generated in soil using the granular product dazomet. Although dazomet can potentially be used as a stand-alone fumigant at higher rates, the optimum sequence of soil moisture for full activation following application without residual phytotoxicity is difficult to achieve. Furthermore, dazomet is currently registered in the U.S. only on nonbearing crops. Experimentation is currently being carried out, however, to use dazomet in sequential applications with other fumigants for the production of runner strawberry plants in nurseries. The idea is to use other fumigants for general pathogen and nematode control in soil and use dazomet to augment control of weeds and volunteer strawberry plants in the upper layers of soil. Metam sodium and dazomet will continue to have useful applications in strawberry production, but most likely they will be used in conjunction with other soil fumigants that give greater or more consistent pathogen control.

CHEMICAL ALTERNATIVES REQUIRING FURTHER DEVELOPMENT

Among the growing list of chemicals proposed as alternatives to MB for soil fumigation, methyl iodide and propargyl bromide currently stand out for having chemical reactivities and spectrums of biological activity in soil that are similar to those of MB (Ohr *et al.* 1996; Yates & Gan 1998). It is important to note, however, that nether methyl iodide nor propargyl bromide is registered with the U.S. EPA as a pesticide or soil fumigant. Like MB, methyl iodide appears to have some synergy with chloropicrin in killing fungi, and most recent trials of methyl iodide for strawberry have used 50/50 mixtures of methyl iodide with chloropicrin. For example, when this mixture was drip applied into beds at 224-336 kg/ha, it gave berry yields almost equivalent to those obtained with standard MB/chloropicrin fumigation (Ajwa *et al.* 2001). Similar drip applications also controlled inoculum of *Verticillium dahliae* buried at depths of 15 and 30 cm, but control at deeper depths was somewhat less than with the MB (Duniway, unpublished). However, in strawberry nursery experiments where a 50/50 mixture of methyl iodide and chloropicrin was shank applied by standard broadcast methods, it worked as well as the MB/chloropicrin standard in reducing inoculum of *V. dahliae* buried in soil and nearly as well for runner plant production (Duniway, unpublished). Baring unforseen complications, methyl iodide may become an important alternative to methyl iodide for soil fumigation.

Propargyl bromide is physically unstable and in recent years has been formulated in 20% toluene for handling, but more acceptable carriers are now being used. Recent trials show that propargyl bromide can be a very effective soil fumigant. For example, in an experiment near Watsonville, California, application of 134-201 kg/ha to preformed beds through drip systems gave strawberry yields nearly equivalent to those obtained with MB/chloropicrin; propargyl bromide also gave a high level of Verticillium wilt control in this experiment (Ajwa *et al.* 2001). Although propargyl bromide has a high level of activity as a biocide in soil, the status of the toxicological information needed for U.S. EPA registration is unclear, and there are many hurdles to overcome for propargyl bromide to become a registered and available soil fumigant.

CONCLUSIONS

Among the known chemical alternatives to MB, chloropicrin, 1,3-D, and metam sodium are the only ones currently registered and available in the U.S. that have enough broad-spectrum activity to be considered as current replacements for MB in soil fumigation. None of these three, however, can be considered to be an equivalent replacement for MB in most soil applications, and they are likely to be used in mixed or sequential applications. Two additional alternatives, methyl iodide and propargyl bromide, have strong fumigant activities in soil that approach those of MB. While these compounds are currently being developed as soil fumigants, they are not registered and we do not know when, or even if, they will actually become available as commercial fumigants. Improved methods of soil fumigation (e.g., drip application, less permeable plastics) with the alternatives known at this time are likely to become important in the next few years.

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ALTERNATIVES TO METHYL BROMIDE FOR USE IN STRAWBERRY PRODUCTION AND NURSERIES IN SPAIN

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ABSTRACT

Strawberries have been the target of research to find alternatives as this crop is the largest single consumer of methyl bromide (MB) in Spain using 800 tonnes for fruit production and 237 tonnes in mother plant production. Based on the most promising results from 4 years of trials on fruit production, a large-scale demonstration programme will be established in 2002 in five different locations in Huelva that will investigate the effects on pathogen control of Telopic (40 cc/m^2 and 20 cc/m^2 VIF), Dazomet (50 g/m^2), solarization with simultaneous shank-application of metam sodium (75 cc/m^2) and simultaneous biofumigation (5 kg/m^2 of chicken manure). Based on the most promising results from 4 years for trials on mother plant production, shank-applied MB-PIC (50-50) (20 g/m^2) under VIF film performed well. 1,3-dichloropropene with chloropicrin (61-35) was a potential alternative to MB rather than Dazomet, metam sodium or metam potassium. Further research is required in order to elucidate suitable alternatives for mother plant production without the use of MB.

Keywords: MB, alternatives, non-chemical, chemical, mixed, results, trends, diffusion.

INTRODUCTION

Strawberry cultivation is the largest MB, pre-plant consumer in Spain. In 1995, the total MB consumption in Spain was 4,633 tonnes of which 1,227 tonnes was used in strawberry fruit production and 498 tonnes in high-elevation nurseries (Varés, *pers. com.*). In 2000, the total MB consumption was 2,377 tonnes of which 800 tonnes was used for fruit production and 237 tonnes in nurseries (Noval, *pers. com.*). Therefore, finding alternatives to MB for strawberry production is as important goal for Spain as it is for the other strawberry-production countries such as the USA (California, Florida), Italy and France. The high MB consumption statistics have made strawberries the main crop in the Spanish National Project INIA SC 97-130 “Alternatives to the Conventional use of MB Environmentally Safe and in a Cost Effective Manner” in Castile-Leon (high elevation nurseries), Huelva (fruit production) and Valencia.

METHODS – FRUIT PRODUCTION

In Huelva, the National Project INIA funded a four years of experiments (1997/98, 1998/99, 1999/00, 2000/01) in two important locations (Moguer and Cartaya) on the coast. In connection with the main grower’s organization Freshuelva, two Farms were selected: “Fresrica-Alconeras SAT”, located at Avitorejo (Moguer) and “Aguas Buenas-Torreagro SA”, located at Tariquejo (Cartaya). Both Farms were of medium-high size and at an appropriate technological level.

An unique and permanent randomized complete block model was established with three large replicates to study machinery movements and to visualize agronomic behaviour easily in “real scale”. Non-artificial soil inoculation was used with the main soil-borne strawberry pathogens that were inoculated on a “natural scale”. Thirteen treatments were selected in March-April of 1997, including controls without fumigation, standardized shank-application of MB, short-term chemical, non-chemical and mixed alternatives, as well as MB dose reduction that would allow compliance with the phase-out schedule up to 2005.

The “dynamic character” of the treatments consisted of allowing each alternative to remain in the same replicate every year, but some additional variable was introduced such as a variation in the application technique, dose and/or period of application (Table 1). This “dynamic character” improved the experiments but created a serious problem for the final statistical analyses of four years of results. In fact, important interactions have been shown between location and year factors. We are working now with a sophisticated statistical analysis AMMI (Additive Main effect and Multiplicative Interaction) to overcome these structural obstacles. Nevertheless, it is possible to propose that the tendencies reported by standard variance analysis from year to year and/or location to location would not differ too much from the likely conclusions of AMMI annalyses. Therefore, “real scale”, “natural scale” and “dynamic character” of the treatments are the “steady conditions” in these experiments. The materials and methods, soil-borne pathogen control, efficacy against weeds, herbicide use, and morphologic and agronomic results as well as provisional trends, have all been presented in other international and domestic forums (López-Aranda 1999a, 1999b; López-Aranda *et al.* 2000a, 2000b, 2001a, 2001b, 2001c).

Table 1: Trials on alternatives to methyl bromide in strawberries (Huelva) from 1997/2001.

TREATMENT	1997/98	1998/99	1999/00	2000/01
A	Control	Control	EMF	EMF
B	MB(40g) broadcast (67/33). Standard.	MB(40g) broadcast (67/33). Standard.	MB(40g) broadcast (67/33). Standard.	MB(40g) broadcast (67/33). Standard.
C	Solarization (6 weeks)	Solarization (5 weeks)	Solarization (4 weeks)	Solarization (4 weeks)
D	Sol.+MB(10g) broad. (67/33)	Sol.+MB(10g) broad. (50/50)	Sol.+MB(10g) broad. (50/50)	Telopic(20cc) VIF preform.
E	Sol.+MS(50cc)	Sol.+MS(100cc)	Sol.+MS(75cc)	Sol.+MS(75cc)
F	Sol.+Biofumigat.	Sol.+Biof.+*Brassica*	*Brassica*+Biofum.	*Brassica*+Biofum.
G	Control	Control	Control	Control
H	MB(40g) broadcast (67/33)	MB(40g) preformed beds (50/50)	MB(40g) preformed beds (50/50)	MB(40g) preformed beds (50/50)
I	MB (40g) preformed(67/33)	MS (125cc) Preformed beds	MS (175cc) Preformed beds	MS (175cc) Preformed beds
J	MB(20g)VIF broadcast (67/33)	Dazomet (50g) broadcast	Dazomet (45g) broadcast	Dazomet (50g) preformed beds
K	MB(20g)VIF preformed (67/33)	MB(20g)VIF preformed bed (50/50)	MB(20g)VIF preformed bed (50/50)	MB(20g)VIF preformed (50/50)
L	TeloneC17 (60cc) broadcast	Telopic (40cc) broadcast	Telopic (40cc) preformed bed	Telopic (40cc) preformed
M	Pic alone (40g) broadcast	Pic alone (40g) broadcast	Pic alone (40g) preformed beds	Pic alone (40g) Preformed beds

Conventional practices for annual strawberry production were followed. Planting with cv. “Camarosa” was carried out in the last week of October every year. Fruit were picked for the fresh market from beginning of February until mid-May.

RESULTS – FRUIT PRODUCTION

The sanitary status of the trials was normal during the four seasons. No lethal soil-borne fungi appeared, only small concentrations of black root rot (*Pythium* spp.) were identified, without significant differences among treatments at both locations. However, increasing populations of *Meloidogyne* spp. with high index of severity in plants were found in controls (A, g) and metam sodium (MS) (i) treatments at Cartaya location. Treatments were classified in a ranking between 1º to 13º for eight morpho-agronomical traits (% of plant survival, early and total yield, early and total fruit size, weed control, plant diameter and number of trifoliate leaves) on each experiment (4 years by 2 locations). The total commercial yield is presented in Table 2. Final ranking average for these traits are summarized in Table 3.

Table 2: Ranking for total commercial yield until mid-May in strawberries (Huelva) for the trials conducted in the period 1997/2001.

Treatment	1997/98		1998/99		1999/00		2000/01		Av.
	Moguer	Cartaya	Moguer	Cartaya	Moguer	Cartaya	Moguer	Cartaya	
L	3º	2º	5º	1º	1º	2º	2º	5º	2.6
H	4º	7º	4º	7º	2º	1º	1º	2º	3.5
M	1º	4º	2º	5º	4º	9º	3º	3º	3.9
K	8º	1º	1º	10º	5º	3º	4º	4º	4.5
D	9º	3º	9º	3º	7º	5º	6º	1º	5.4
J	5º	9º	3º	9º	3º	4º	5º	10º	6.0
B	6º	8º	6º	4º	6º	8º	7º	6º	6.8
E	10º	6º	8º	2º	8º	6º	8º	7º	6.9
I	2º	5º	7º	6º	9º	7º	11º	9º	7.0
F	12º	10º	13º	8º	10º	10º	9º	8º	10.0
C	11º	11º	10º	11º	12º	11º	13º	11º	11.3
G	7º	13º	11º	13º	11º	13º	12º	12º	11.5
A	13º	12º	12º	12º	13º	12º	10º	13º	12.1

Table 3: Ranking average summary of morpho-agronomic traits in strawberries in trials from 1997/2001.

Treatments	Total commercial yield	Early commer-cial yield	Final fruit size	Early fruit size	Weed elimin-ation	% survival	Plant diameter	Leaves per plant	Final ranking average
L	2.6	4.8	2.4	2.3	3.4	4.8	4.6	3.9	3.60
H	3.5	5.0	4.6	3.9	2.4	8.5	5.9	6.8	5.07
K	4.5	4.1	4.9	4.5	3.6	8.0	6.0	5.3	5.11
B	6.8	4.4	4.6	4.8	7.8	7.8	2.4	2.6	5.15
M	3.9	4.6	4.3	5.0	4.9	5.8	7.0	6.8	5.29
D	5.4	4.9	6.6	6.6	8.4	6.6	4.3	4.3	5.88
J	6.0	4.3	6.0	6.4	5.4	6.6	6.0	6.8	5.93
E	6.9	6.0	7.3	7.8	8.3	7.5	6.8	7.0	7.20
I	7.0	8.0	6.8	7.0	3.6	7.5	9.1	9.0	7.25
F	10.0	9.6	10.0	9.1	12.0	8.1	8.1	7.1	9.25
C	11.3	11.0	10.5	10.0	9.4	6.5	9.0	10.6	9.78
A	12.1	11.9	12.1	10.6	12.0	6.0	10.6	9.9	10.65
G	11.5	12.5	11.0	11.9	10.0	7.4	11.0	11.1	10.80

This consistent result supports the view that short-term alternatives to MB exist for the strawberry industry in the area of Huelva (L, M, D, J). These new, short-term alternatives to MB were cost-effective.

After four years work, the National project INIA SC 97-130 has started in 2002 with a real scale demonstration programme including Telopic (40 cc/m^2 and 20 cc/m^2 VIF), Dazomet (50 g/m^2), solarization with simultaneous shank-application of MS (75 cc/m^2) and simultaneous biofumigation (5 kg/m^2, chicken manure) in five different locations in Huelva.

METHODS - MOTHER PLANT PRODUCTION

The National Project INIA framework funded four years of experiments (1998, 1999, 2000, 2001) at different locations (Cabeza de Alambre, Arevalo, Vinaderos-1 and Vinaderos-2) in Avila and (Navalmanzano-1, 2, 3 and 4) in Segovia provinces in the Castile-Leon region. The results and trends were presented in international and domestic forums (Melgarejo *et al.* 2001a, 2001b).

This paper reports on the characteristics of high-elevation nurseries, experiments trialled, chemical treatments, the material and methods for these experiments, soil-borne pathogens control and provisional trends. It complements research carried out that focused on agronomic traits (yield).

RESULTS AND DISCUSSION - MOTHER PLANT PRODUCTION

Table 4 shows that the agronomic results ($P < 0.5$) were not consistent. The characteristics of each high-elevation nursery e.g. geographic mobility, previous crops, winter period of fumigant treatments and planting dates, resulted in different trends observed for each year and in each location. Nevertheless, these results allow some conclusions to be drawn:

a) Shank application treatments using MB-PIC (50-50) (20 g/m^2) under VIF film technology performed well;

b) 1,3-D+PIC (61-35) was a potential alternative to MB rather than Dazomet, metam sodium or metam potassium.

c) Further research is required in order to elucidate suitable alternatives for methyl bromide.

Table 4: Commercial runner plants harvested per m^2. High-elevation nurseries. 1998-2001.

	1998		1999		2000		2001	
Treatments	**C.Alam.**	**Naval.-1**	**Arevalo**	**Naval.-2**	**Vina.-1**	**Naval.-3**	**Vina.2**	**Naval.-4**
Control	13.1c	18.4 c	42.3 a	44.5 c	48.7 a	17.0 c	44.7 b	11.7 b
MB (40g)	52.9 a	47.6 a	52.2 a	51.3 bc	67.0 a	67.0 ab	62.7 a	78.0 a
MB (20g) VIF	55.4 a	43.9 ab	54.2 a	53.2 bc	63.3 a	82.7 a	50.3 b	69.3 a
Telone C17 (40cc)	46.1 ab	41.3 ab	-	-	-	-	-	-
Telopic (35/40cc)	38.6 b	38.0 ab	50.8 a	69.0 a	52.7 a	53.0 b	50.3 a	71.7 a
Pic alone (40g)	38.3 b	35.4 b	52.7 a	51.3 bc	62.3 a	66.0 ab	-	-
Dazomet (50g)	-	-	42.3 a	44.5 c	55.0 a	58.3 b	49.7 b	66.0 a
MS (125cc)	-	-	-	-	53.0 a	63.0 b	58.0 a	28.7 b
MP (160cc)	-	-	-	-	68.3 a	61.7 b	47.7 b	33.7 b
Telopic (20cc) VIF	-	.	-	-	-	-	64.7 a	70.0 a

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THE IMPORTANCE OF DISEASE-FREE PLANTS PRODUCED IN STRAWBERRY NURSERIES IN SPAIN

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ABSTRACT

Spain is the most important country producing strawberry runner plants in Europe. Phytosanitation in the nurseries is essential in order to produce disease-free plants. The future ban of methyl bromide (MB) in European countries in 2005 has stimulated the search for alternatives to this soil biocide. Within the framework of the National project INIA SC 97-130, several chemical treatments were trialled in different high elevation nurseries of Castilla-León (Spain) over a four year period. The use of disease-free mother plants and the need to apply treatments to sterilize the soil were considered essential for obtaining disease-free runner plants from the nurseries. Dazomet and 1,3-dichloropropene:chloropicrin (61:35) were considered potential alternatives to MB as soil fumigants.

Keywords: chloropicrin, dazomet, dichloropropene, metam potassium, metam sodium, methyl bromide, strawberry nurseries.

INTRODUCTION

Strawberry high-elevation nurseries in Spain occupy a land area of about 1,100 ha and produce 500 to 550 million commercial runner plants per year. It is the most important runner plant production area in Europe. The high-elevation nurseries are located in sandy and flat areas of Castilla-León (Central Northern part of Spain), about 800 - 1,100 m above sea level, with a continental climate.

The cultivation system is annual with plantation dates between April and May and digging of fresh commercial runner plants in October. Ninety five per cent of mother plants come from big California nurseries. The general phytosanitary status of the Spanish high-elevation nurseries is satisfactory because nurseries are usually treated with methyl bromide (MB) to control *Phytophthora cactorum*, *Verticillium* spp., phytoplasmas and weeds. In 2005, MB will be banned in European Union countries because of its depletion of the ozone layer. Alternatives to this biocide should be found in order to continue to obtain disease-free strawberry plants in nurseries. In this paper, we describe the results obtained in the framework of the National Project INIA SC 97-130 on alternatives to MB in Spanish strawberry nurseries.

MATERIALS AND METHODS

Experiments were carried out over four years (1998-2001) in collaboration with two nurseries (Viveros California SAT and Viveros Rio Eresma SA), on their farms located at different locations in Avila (Spain) and Navalmanzano (Segovia, Spain), respectively. Experimental fields were different each year because in this crop it is usual to lease farms in different locations from time to time. Previous crops grown were strawberry in 1988 and 1989 (the soil was disinfested with MB before plantation); sugar beet at Navalmanzano; cereals at Avila in 2000; potato at Navalmanzano; and cereals at Avila in 2001.

A randomised complete block design with three replicates was established in each field. The size of each experimental unit was 400 m^2 (5.5 m wide, with 3 rows of mother plant cv. “Camarosa” coming from California nurseries (USA), and 72 m long). Treatments were applied on 24/3/1998, 26/4/1999, 22/3/2000, and 29/3/2001 at Avila fields; and on 30/3/1998, 9/4/1999, 5/4/2000, and 30/3/2001 at Navalmanzano fields. Plants were planted and harvested, respectively, on 22/4/1998 and 8/10/1998; 30/4/1999 and 14/10/1999; 18/4/2000 and 7/10/2000; and 26/4/2001 and 18/10/2001 at Avila fields;

and on 24/4/1998 and 13/10/1998; 9/4/1999 and 14/10/1999; 16/5/2000 and 7/10/2000; and 7/5/2001 and 25/10/2001 at Navalmanzano fields.

The Ttreatments were: T1: Control without soil fumigation; T2: MB:chloropicrin (MB-Pic) (67:33 in 1998 or 50:50 in 1999,2000 and 2001) 40 g/m^2 broadcast shank-applied under transparent PE film; T3: MB-Pic (67:33 or 50:50) 20 g/m^2 broadcast shank-applied under VIF transparent film; T4: 1,3-dichloropropene:chloropicrin (DD-Pic) (78:17) 40 cm^3/m^2 broadcast shank-applied; T5: DD-Pic (61:35) 35 cm^3/m^2 broadcast shank-applied; T6: DD-Pic (61:35) 17.5 cm^3/m^2 broadcast shank-applied under VIF transparent film, T7: chloropicrin 40g/m^2 broadcast shank-applied under transparent PE film; T8: Dazomet 50 g/m^2 incorporated and after tarped with transparent PE film; T9: Metam-sodium 125 cm^3/m^2 broadcast shank-applied under transparent PE film; and T10**:** Metam**-**potassium 160 cm^3/m^2 shank applied under transparent PE film.

Soil from each field was analysed before (16/3/1998, 17/3/1999, 14/3/2000, and 28/3/2001) and after treatments (14/4/1998, 29/4/1999, 28/4/2000, and 26/4/2001). Twenty samples were taken from the first 0.15 cm depth soil in each plot and mixtured. Ten g aliquots were dissolved in 90 ml sterile distilled water contained in 250-ml flasks and shaken for 30 min at 150 rpm.; 10-100 fold dilutions were made, and aliquots (100μl) from undiluted and diluted suspensions were spread onto Petri plates containing potato-dextrose agar (PDA) and selective media for *Fusarium, Phytophthora*, *Pythium, Rhizoctonia*, and *Verticillium* (Jeffers & Martin 1986; Morris *et al.* 1995; Nash & Snyder 1962; Sumner & Bell 1982). Three replicates were made for each plot/media and dilution. Petri dishes were incubated at room temperature for 5-7 days and the colonies were counted. Dry weight of soil samples was calculated in 5 g subsamples. The total colony forming units per gram of dry soil (cfu/g) of soil fungi, *Fusarium, Phytophthora, Pythium*, *Rhizoctonia* and *Verticillium* were estimated in each plot. Fungi in plates containing PDA were identified by using appropriate taxonomic keys. Populations were log transformed and then analysed by analysis of variance when the F-test was significant at P= 0.05, treatment means were compared by the Student-Newman-Keul's multiple range test. Samples were also analysed for populations of nematodes following the method of Oostenbrink (1960).

Three hundred and sixty mother strawberry plants coming from California (USA) to each of the fields were analysed each year, except for 1998 when only ten plants were analysed in each field. Plants were cut into two longitudinal pieces and each half was incubated in Petri plates (130cm diam) containing moistened filter paper for two days or 10 ml of distilled water and ten immature carnation petals for seven days and then observed under the light microscope**.**

On three occasions during the strawberry growing period (initial running, full production, and harvest), plants were sampled to observe their phytosanitary state. Samples were taken on 23/6, 30/7, 22/9, and 14/10 in 1998; 22/7, 29/9 and 14/10 in 1999; 5/7, 8/9, and 16/10 in 2000, and 3/7, 7/8, and 9/10 in 2001. Twenty plants were randomly chosen from the centre row in each plot, and then analysed in the laboratory, as described above. The incidence of diseased plants was calculated for each treatment (%), and the results were analysed by analysis of variance. When the F-test was significant at P= 0.05, treatment means were compared using the Student-Newman-Keul's multiple range test.

RESULTS

Despite the uneven distribution of fungal populations in the plots, all treatments at Navalmanzano in 1999, 2000 and 2001, and at Avila in 2000 and 2001 reduced the total number of fungal colonies (Table 1). The qualitative study of the potentially pathogenic fungal populations in the soil showed that the fields usually had colony forming units of *Fusarium, Verticillium*, and *Pythium*, and in some cases *Rhizoctonia* (Navalmanzano and Avila 2001) and *Phytophthora* (Navalmanzano 1999; 2000, 2001; Avila 2000, 2001). The treatments reduced the populations of these genera and in some cases eliminated them.

Table 1: Total fungal populations (colony forming units x 10^3/gr dry weight of soil) in soils at two different field during 4 years before and after treatments[1]

TREATMENTS[2]	YEARS							
	1998		1999		2000		2001	
	Before	After	Before	After	Before	After	Before	After
NAVALMANZANO								
T1: Control	214 a	112 a	3210 a	630 a	16 a	128 a	23 a	197 a
T2:MB-Pic	154 a	5 a	2700 b	10 c	10 a	6 c	45 a	0.5 d
T3:MB-Pic +VIF	307 a	10 a	436 c	6 c	30 a	23 b	29 a	2 cd
T4:DD-Pic (78:17)	133 a	27 a	NT	NT	NT	NT	NT	NT
T5: DD-Pic (61:35)	280 a	8 a	1260 b	4 c	16 a	11 c	30 a	8 b
T6:DD-Pic (61:35)+VIF	NT	NT	NT	NT	NT	NT	32 a	2 cd
T7:Chloropicrin	160 a	28 a	2870 b	24 b	41 a	7 c	NT	NT
T8: Dazomet	NT	NT	1960 b	38 b	6 a	13 c	236 a	1 cd
T9:Metam sodium	NT	NT	NT	NT	17 a	19 b	42 a	6 b
T10:Metam potassium	NT	NT	NT	NT	71 a	9 c	32 a	3 c
AVILA								
T1: Control	136 a	41 a	1810 ab	186 a	39 a	90 a	21 a	27 a
T2:MB-Pic	130 a	1 a	1180 a	107 a	186 a	3 d	27 a	3 b
T3:MB-Pic+VIF	220 a	6 a	1290 a	116 a	116 a	16 c	26 a	1 bc
T4:DD-Pic (78:17)	81 a	10 a	NT	NT	NT	NT	NT	NT
T5:DD-Pic (61:35)	95 a	0.05 a	3260 bc	180 a	21 a	161 c	35 a	3 b
T6:DD-Pic (61:35)+VIF	NT	NT	NT	NT	NT	NT	21 a	3 b
T7:Chloropicrin	273 a	1 a	1720 ab	83 a	104 a	26 b	NT	NT
T8: Dazomet	NT	NT	8200 c	27 b	138 a	0.3 e	25 a	0.3 c
T9:Metam sodium	NT	NT	NT	NT	1770 a	15 c	25 a	0.5 bc
T10:Metam potassium	NT	NT	NT	NT	1300 a	17 c	32 a	0.5 bc

[1]Data are the mean of three replicates. Means followed by the same letter in each column in each field is not significantly different (p=0.05) by the Student-Newman-Keul's multiple range test. NT = non tested. [2] See Materials and Methods for details of treatments.

Analysis of mother plants coming from California (USA) showed infection by *Phytophthora cactorum* (2-7%) , *Botrytis cinerea* (1-40%), and *Fusarium* spp. (0.5-10%)

Differences in the percentage incidence of diseased plants were observed between treatments and control at Navalmanzano nurseries in 1999 and 2000 (Table 2). Infections were mostly caused by *Verticillium dahliae* and *Phytophthora cactorum*. In 2001, treatments with MB-Pic, DD-Pic (61:35) and Dazomet reduced disease incidence while metam-sodium and metam-potassium did not (Table 2). *V. dahliae* and *P. cactorum* were also the pathogens mostly isolated from diseased plants. Very few diseased plants were obtained from the Avila fields, except in 1998 (Table 2). In this year, most of the infections were caused by *P. cactorum* in both the nurseries.

Table 2: Percentage of incidence of diseased plants[1]

TREATMENTS[2]	YEARS			
	1998	1999	2000	2001
NAVALMANZANO				
T1: Control	14 a	25 a	62 a	48 a
T2: MB-Pic	11 a	0 b	2 b	7 b
T3:MB-Pic+VIF	12 a	0 b	0 b	3 b
T4:DD-Pic(78:17)	21 a	0 b		
T5:DD-Pic(61:35)	14 a	0 b	3 b	5 b
T6:DD-Pic(61:35)	NT	NT	NT	8 b
T7:Chloropicrin	31 a	0 b	NT	NT
T8: Dazomet	NT	NT	5 b	15 b
T9:Metam sodium	NT	NT	7 b	31 ab
T10:Metam potassium	NT	NT	3 b	36 ab
AVILA				

TREATMENTS[2]	YEARS			
	1998	1999	2000	2001
T1: Control	26 a	2 a	5 a	10 a
T2:MB-Pic	7 a	0 a	2 a	2 b
T3:MB-Pic+VIF	12 a	0 a	0 a	0 b
T4:DD-Pic(78:17)	7 a	0 a	NT	NT
T5:DD-Pic(61:35)	14 a	0 a	0 a	0 b
T6:DD-Pic(61:35)+VIF	NT	NT	NT	0 b
T7:Chloropicrin	12 a	0 a	0 a	NT
T8: Dazomet	NT	NT	0 a	2 b
T9:Metam sodium	NT	NT	2 a	2 b
T10:Metam potassium	NT	NT	0 a	3 b

[1]Data are the mean of three replicates. Means followed by the same letter in each column in each field is not significantly different (p=0.05) by the Student-Newman-Keul's multiple range test. NT = non tested. [2] See Materials and Methods for details of treatments.

Nematodes were abundant at all locations but inside the normal population limits. At Navalmanzano, the population consisted of non-parasitic Rhabditidae and Dorilaimidae, Mononquidae and a low proportion of Tylenquidae from diverse genera (*Aphelenchus* spp, *Seineura* spp., *Tylenchus* spp., *Tylenchorhynchus* spp., *Pratylenchus* spp., and *Neotylenchus* spp.), none of them being parasitic on strawberry. At Avila, the populations were *Pratylechus zeae*, *Heterodera avenae*, *Globodera* spp. and *Punctodera* spp., together with other Tylenchidae and Rhabditidae. In all locations, parasites of strawberry were detected. All the chemical treatments reduced nematode populations. Sampling at different dates did not reveal nematode damage in any year in any field.

DISCUSSION AND CONCLUSIONS

Four years of experiments have highlighted the special requirement to find viable alternatives to MB for use in strawberry high-elevation nurseries. The results showed that it was necessary to fumigate the soil in which the runner plants are to be cultivated. Disease incidence was significant in fields where no soil sterilization was done in previous years of the experiment (Navalmanzano 1999, 2000, 2001), while few problems occurred when the soil was fumigated in the previous crops (Navalmanzano 1998, Avila 1998, 1999).

Strawberry nurseries are characterized by a high geographic mobility due to farm-leasing arrangements which could result in nurseries being established in non-sterilised soils from the previous year. Results also showed that it was necessary to take special care with mother plants coming from other nurseries. Infections of *P. cactorum* in the runner strawberry plants at two locations in 1998 were caused by pathogens coming from mother plants since no *Phytophthora* was detected in the soil that year.

These results demonstrate clearly that other chemical alternatives to MB are possible in high-elevation nurseries in Castilla-León, including dazomet and DD-Pic (61:35). There were also good results with shank applied MB-Pic (50:50) at a reduced dose (20 g/m^2) under VIF film technology. This latter result could be very important for justifying the continued use of MB as a 'critical use' after 2005 in high-elevation strawberry nurseries.

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ALTERNATIVES TO METHYL BROMIDE IN VEGETABLE AND STRAWBERRY CROPS IN SPAIN

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ABSTRACT

Alternatives to Methyl bromide (MB) have been studied in seven locations along the whole Valencian country (Spain). Among the treatments was a dosage reduction of MB by VIF sheet or 50% mixture with chloropicrin, two mixtures of 1,3-dichloropropene and chloropicrin, 32.7% and 52.8%, double treatment with 1,3-dichloropropene followed by metam-Na (MS), basamid, manure and solarization combined with manure, MS or ammonium fertilisers. Strawberry, pepper, artichoke, potato, watermelon, onion, and earth almond are among the crops grown after disinfestation. Soil sickness, *Phytophthora capsici, Fusarium oxysporum*, *Sclerotinia minor* and *Verticillium dahliae* were the soil problems to be controlled.

Dosage reduction of MB were very good treatments but they will not be allowed after 2005 phase out except for critical uses. The mixture 1,3-dichloropropene and chloropicrin seemed a good chemical alternative if the application technique and soil preparation was done carefully, in heavy soils this treatment was sensitive to compaction. Basamid and MS did not produce good results comparable to MB, in any experiment, but it was always better than the control. High rates of organic matter amendment produced phytotoxicity in this kind of soil at the used rates. Solarization with manure is a good alternative if the manure is moderated to mininise the risk of water table contamination. The best option seemed to be rotation alternatives to maintain yield.

Keywords: 1,3-Dichloropropene, Chloropicrin, Metam-Na, Solarization, organic amendment, soil sickness, *Fusarium*, *Phytophthora*, *Verticillium*.

INTRODUCTION

Soil disinfestation is a practice considered necessary in most intensive vegetable crops, especially in monoculture such as pepper and strawberry. Physical treatment based on steam became very expensive with the increase of fuel price, and methyl bromide (MB) has been selected as the main choice for soil disinfestation because of its broad spectrum of activity against most soilborne parasites. Farmers have for a long time appreciated the beneficial effect on a crop grown pathogen-free using MB as a part of the standard soil preparation treatment.

MB will be phased out after 1st January 2005 except for those uses named as critical. Therefore there is necessary to search for new alternatives and also to reduce the dosage of MB (Cebolla et al. 1995) and to improve the technique of application for those uses. The use of brasica roots as biofumigation source (Angus et al. 1994) has been proposed because of the release of alylisothiocyanates, but also some biotoxic volatile compounds (Gamliel & Stapleton 1996) generated in organic amended soils to improve the effectiveness of soil solarisation.

Alternatives to MB selected for testing were 1,3-dichloropropene (known for its nematicidal effects); chloropicrin (known for its fungicidal effect); Metam-Na (MS) and basamid which act mainly as sources of methyl-iso-thiocianate; and some mixtures of these chemicals or combination with solarization.

MATERIALS AND METHODS

Seven experiments had been established in order to study the alternatives to MB for horticultural crops in the Valencian country, Mediterranean coast of Spain. The fields were chosen because a clear history of repeated crops with at least a remarkable soil sickness Dosages applied per treatment and experiment are described in Table 1. The first experiment lasted from 1998 to 2001 and consisted of repeated crops of strawberries at La Canal de Navarrés “La Canal” disinfested with the same system every year in the same plot. Some alternatives were compared to the standard MB at 60g/m^2 “Br60” and a non disinfested control “Control”. Among the treatments there was a dosage reduction of MB at 30 g/m^2 by the use of Virtually Impermeable Film "BrVIF"; Solarization in a soil amended with a mixture of 75% sheep manure and 25% chicken manure at the rate of 5kg/m^2. Metam sodium at 144 g/m^2 (MS) was applied to the irrigation water without a tarping sheet, and finally a treatment with the sole addition of a large amount of manure 15 kg/m^2,"Biof" (the same mixture as before) without solarization tarp. In 2000, a new solarization treatment was introduced in which soil was amended with 5 kg/m^2 of sheep manure and complemented with 80 g/m^2 of ammonium sulphate to compensate for the total Nitrogen content of treatment "Sol+Man".

The second experiment, only during the year 1999, added new treatments in a strawberry field. A mixture of 1,3-dichloropropene and chloropicrin 35% at 28 g/m^2 "Tel+Clo" was applied with the drip irrigation system water. A double disinfestation, first with 1,3-dichloropropene (Telone II) at 18 g/m^2 and 3 days later with MS at the rate of 108g/m^2, compared with a standard "Br60" and "Control".

The third experiment, with a duration of two years, in a strawberry field at "Montesa" included a mixture of MB and chloropicrin 50% at 40 g/m^2 "Br50"; a mixture of 1,3-dichloropropene 55.4% and chloropicrin 32.7% (Agrocelhone NE) at a rate of 40 g/m^2; and a double treatment of Telone II at 18 g/m^2 followed by MS at 108 g/m^2 with a 5 day interval among treatments. This treatment was repeated in 2000 by application, through irrigation pipes, than applied over one half of the surface, while the plants of previous crop were still alive "Tel&MSC". Basamid was applied at a rate of 50 g/m^2 distributed over the soil surface, mixed with a deep rototiller and tarped with a polyethylene sheet. The disease problem in strawberry fields was soil sickness due to a soil complex in which *Fusarium oxysporum* participated as main component, showing wilt symptoms and vascular discoloration only by the end of the crop.

A fourth experiment in a field with an horticultural crop rotation history that included earth almond crop at Alboraia, Valencia central coast. The treatments, as described before, were "Br60" at 60 g/m^2; "BrVIF" at 30 g/m^2; "Sol+Man" 5 kg/m^2; "Sol+MS" 72g/m^2; Telone II at 18 g/m^2 followed by MS at 108 g/m^2 7 days latter "Tel&MS", applied by flood irrigation water under the tarp sheet, and "Tel+Clo" at 50g/m^2 mechanical application. After disinfestation a sequence of escarole, potato, watermelon, onion, potato, earth almond were grown. The problems to solve in this field were residual tubers of earth almond (*Cyperus esculentus*) from the previous crop acting as a weed in the next summer crop, and the presence of *Sclerotinia minor* as a pathogen of escarole.

The fifth experiment was at Benicarló in an Artichoke field. The treatments to compare with "BrVIF" were "Sol+Man"; "Sol+MS"; "Tel+Clo", "Tel&MS", and a new mixture of 1,3-dichloropropene 36.7% and chloropicrin 52.8% (Agrocelhone FE) at a rate of 50 g/m^2 "AFE". The soil problem was a wilt due to *Verticillium dahliae*.

At Pilar de la Horadada "Pilar H.Sol", the south of Valencian country, in a typical area of greenhouse pepper crops, the sixth experiment was carried out based on solarization practices, organic amended with 4 Kg of sheep manure + 2 Kg of chicken manure "Sol+Man"; solarization with 150 g/m^2 MS "Sol+MS" and solarization with 80 g/m^2 urea "Sol+Amon". All the mentioned treatments included at least 4 kg/m^2 of sheep manure.

The seventh experiment, at the same site "Pilar H.Chem", was based on chemical alternatives, such as Agrocelhone NE at 50 g/m^2 "Tel+Clo" and Agrocelhone FE at 50 g/m^2 "AFE". These treatments were compared with MB at 40 g/m^2 under VIF sheet "BrVIF" and did not include a non-disinfested control due to the high risk of reinfestation. The problem was *Phytopthora capsici*, and *Meloidogyne incognita* but also non-pathogenic pepper replant problems.

Tarping duration was 5 days for MB treatments, 10 days for treatments based on 1,3-dichloropropene, MS or Basamid and 4-5 weeks for solarization treatments.

The parameters used to compare these alternatives were first quality, second quality, marketable and total yield, vigour as height and diameter for strawberries, average leaf length in artichokes and also a vigour visual index (1-5). Disease incidence and weed incidence was measured as the cost of weeding time.

The biocidal effect of each treatment was tested by using biological probes consisting of polyamide tissue bags containing soil and some small pieces of roots infested by *Fusarium oxysporum*, coming from previous strawberry crop, buried at 10 and 30 cm depth before application, and recovered on selective media after the treatment to monitor inoculum survival.

The statistical comparison among treatments were done by Duncan Test at 95% level.

Table 1: Summary of dosages by treatments and experimental fields

	La Canal	Bolbaite	Montesa	Alboraia	Benicarló	Pilar H. Sol	Pilar H. Chem
Control	Yes	Yes	Yes	Yes	Yes	No	No
Br60	60 g/m^2	60 g/m^2	60 g/m^2	60 g/m^2			
BrVIF	30 g/m^2			30 g/m^2	30 g/m^2	40 g/m^2	40 g/m^2
Br50			40 g/m^2				
Sol+Man	5 kg/m^2			5 kg/m^2	5 kg/m^2	6 kg/m^2	
Sol+MS	(1) 36 g/m^2			72 g/m^2	72 g/m^2	150 g/m^2	
Tel+Clo		28 g/m^2	50 g/m^2	50 g/m^2	50 g/m^2		50 g/m^2
AFE							50 g/m^2
Tel&MS		18 & 108g/m^2	18 & 72g/m^2	18 & 108g/m^2	18 & 72g/m^2		
Tel&MSC			36 & 144g/m^2				
MS	144g/m^2						
Basam			50 g/m^2				
Biof	15 kg/m^2						
Sol+Amon	(2) 80 g/m^2		(2) 80 g/m^2				80 g/m^2

(1). 3rd and 4th years dosage was increased to 72 g/m^2. (2) 1st year applied as ammonium sulphate, 2nd year changed to 35 g/m^2 of Urea as an equivalent N amount.

RESULTS

The most important parameter in the search for alternatives is marketable yield but when comparing different crops we need to standardise the figures. The method used to compare, in Graph 1, is to calculate the percent of yield between control and MB (Br60 or BrVIF), considered as standard, in such a way that if the treatment is better than MB the % results greater than 100% and if it is worse than Control, the result is negative. Graph 1 shows for each treatment and experiment the resultant index %.

The treatment based on dosage reduction of MB by VIF tarp gives a marketable yield similar to standard MB "Br60" with no significant differences. The same consideration has to be made with respect to weed control and plant vigour. Very good control can be observed through biological probes at 10 cm depth, but Br60 seems to disinfest deeper, up to 30 cm.

The other treatment based on dosage reduction of MB by increasing the amount of chloropicrin up to 50% "Br50", used at Montesa experiment during the years 2000 and 2001, gave exactly the same results as "Br60" in all the parameters considered so far.

Graph 1: Percent index of marketable yield between MB reference (100%) and control (0%). Average index of the treatments through the experimental fields.

Inoculum control in the solarization treatments, which got through biological probes, was not as exhaustive as was in MB, but marketable yield from the first year in experiments in "La Canal" and "Pilar H." was excellent. The second year of treatment repetition in "La Canal" gave good plant vigour in strawberries. Marketable yield did not show significant differences compared to the MB treatments, but a small reduction of yield was observed. The results of 2000 and 2001 decreased up to significant different level with reduction of about 200g/plant of strawberries compared with MB. A drop in effectiveness can be appreciated when solarization with this manure mixture is repeated more than two years.

Solarization with MS “Sol+S” was also very interesting during the first year both in La Canal and Pilar H. Marketable yield in Alboraia decreased significantly compared to MB in the first crop of escarole, which was affected by *Esclerotinia minor*. Weed control although not complete reduced significantly the weeding cost.

The mixture “Tel+Clo” gave very good results in Bolbaite, including control of weeds, plant vigour quality and marketable yield, with no significant differences with “Br60”. In other experiments such as those in Montesa and Alboraia, yield and other parameters were worse than in “Br60”, maybe because of a difficulty in the application of treatments, but the results were very good at Pilar H. and Benicarló, with good control of *P.capsici* and *V. dahliae*.

Although there were no significant differences with “BrVIF” or “Br60”, “AFE” gave excellent results at Benicarló and Pilar H., with artichokes and pepper crops respectively. Treatment “Tel&MS” gave very promising results in Alboraia and also in Benicarló, apparently with better results in the control of *S. minor*, but at the same significant level as “Br60” or “BrVIF”.

CONCLUSIONS

“BrVIF” and “Br50” are very good treatments, with high performance but will not be allowed after 2005 phase out except for critical uses (those MB treatments without an alternative). The mixture “Tel+Clo” seemed a good chemical alternative if the application technique and soil preparation is done carefully, especially in heavy soils sensitive to compaction. On the other hand, “AFE” which has been tried only twice in this research programme seemed better than “Tel+Clo” in both Benicarló and Pilar H. experiments but there were no statistically significant differences.

Basamid did not gave promising results maybe beause of problems in the application and distribution of the chemical. MS did not gave good results in any experiment comparable to MB but it was always better than the control. High rates of organic matter amendment “Biof” produced phytotoxicity in this kind of soil at the rates used in “La Canal”.

Solarization with manure was a good alternative if the manure quantity is moderate to minimise the risk of water table contamination. The effect of improved marketable yield could not only be explained by disinfestation but also, in our soils poor in organic matter, by increasing by up to 2% the content in the organic matter and hence its fertility. Unfortunately, the repetition of this treatment for more than two years did not ensure its efficacy and there was a high risk of contamination. The best option seemed to be alternative rotation so that yield was maintained.

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ALTERNATIVES TO METHYL BROMIDE FOR SOIL DISINFESTATION OF STRAWBERRY IN MOROCCO

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ABSTRACT

Methyl bromide alternatives proposed for soil disinfestation of strawberries in Morocco were part of a demonstration project funded by the Multilateral Fund and executed by UNIDO. These alternatives were selected based on their technical and economic feasibility over the course of two cropping seasons and were i) solarization in combination with 1,3-dichloropropene (1,3-D) or metam sodium (MS), ii) Bio-fumigation and iii) Negative pressure soil steam pasteurization. The behavior of 1,3-D and methyl isothiocyanate were studied under field and laboratory conditions to determine their optimal conditions for application.

Keywords: Methyl bromide, 1,3-dichloropropene, metam sodium, soil disinfestation, sandy soil, methyl isothiocyanate

INTRODUCTION

Morocco is a producer and exporter of fresh and frozen strawberry fruit. This crop is considered a high value cash crop for farmers and a source of hard currency for the country. The cultivated area has increased from 205 ha in 1990 to 2,430 ha in 2000, corresponding to an increase in production from 4,582 to 70,830 tonnes. Methyl bromide (MB) is used in soil disinfestations of strawberry to control root-knot nematode, weeds and soil insects. In general, it is applied only on the planting lines at a variable rate from 120 to 280 kg/ha. MB consumption increased from 37 tonnes in 1992 to about 250 tonnes in 2000 (Ammati 1998).

Following ratification of the Montreal Protocol, Morocco was one of the first countries to seek assistance from the Multilateral Fund to implement a demonstration project on alternatives to MB for soil disinfestation of strawberry. The alternatives selected for soil disinfestation are described in this paper are part of the results of a demonstration project, UNIDO MP/126/MOR/97, implemented during the 1998-2000 period.

MATERIALS AND METHODS

Based on the soil pests associated with strawberry production, available chemical and physical alternatives were selected by international and national experts and tested as possible alternatives to methyl bromide. The technical and econiomic faisbality of these alternatives were tested under severe conditions of root-knot nematode and weed infestation within an Integrated Pest Management (IPM) strategy, during 1998-2000 period, in the strawberry production area. These alternatives were applied during summer and their effect on yield and pests were assessed during the production season.

For soil solarisation, the soil temperature was continuously registered at 10 and 30 cm soil profiles using a data logger CPMPEL CR10X. These alternatives were compared in large areas measuring 100m² during the first season and 600 m² in the second. Three replicates were used in in a completely randomised design. In parallel, laboratory studies were carried out to understand the mobility, the persistence in the soil, and the losses to atmosphere of these fumigants.

RESULTS AND DISCUSSION

Yield and performance of alternative

The MB alternatives selected were i) Solarization in combination with dichloropropene (1,3-D) or metam sodium ii) Biofumigation and iii) Negative pressure soil steam pasteurisation (NPSSP). They were selected based on their technical and economic feasibility, especially their impact on root-knot nematode populations (Table 1), on weeds (Table2), on yield performance (Table 3) and their economic return (Table 4) compared to MB.

Table 1: Effect of Methyl Bromide alternatives on root-knot nematodes (*Meloidogyne javanica* juveniles/500 g of soil), during two crop seasons 1998-99 & 1999-00

Selected alternatives	Before application	After application
Control	450	292
Methyl bromide	360	00
Solarisation. (6wks)	380	00
Metam sodium+Solarisation. (4wks)	385	00
1,3 D+Solarization (4wks)	380	00
Negative Pressure Steam Soil Pasteurization	335	00

Following soil disinfestation during summer and prior to planting, the selected alternatives eliminated initial root-knot nematode populations and gave similar results to MB. However, following planting, during the production season nematodes populations were exposed to cold soil temperatures and were maintained below the economic threshold. At the end of the season in May-June, the yield was already established and late infections affected the roots but not the production.

Table 2: Effect of Methyl Bromide alternatives on weeds during two crop seasons 1998-99 & 1999-00

Selected alternatives	Weed density (plants/m²)	Fresh biomass (g/m²)	Dry biomass (g/m²)
Control	92	1450	125
Methyl bromide	0	0	0
Solarisation. (6wks)	25	338	24
Metam sodium+Solarisation. (4wks)	0	0	0
1,3 D+Solarization (4wks)	0	0	0
Negative Pressure Steam Soil Pasteurization	0	0	0

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Weeds are considered as the major constraint for strawberry production compared to other pests. Among 14 species identified in the production area, *Cynedon dactylon* and *Cyperus rotundus* are the most important economic pests. The selected alternatives gave good control of these weeds. However, metam sodium combined with solarisation showed similar efficacy with MB on these two species, even during the cropping season.

The economic feasibility of the selected alternatives were assessed based on their effect on yield. Because the planting density per hectare was variable, the yield was expressed per plant**.** The selected alternatives increased relative yield compared to the control. The performance of these alternatives did not differ statistically from MB.

Costs were basically estimated on labour involved prior, during and after application of each selected alternative, the chemical, plastic, fuel and organic manure necessary to accomplish each alternative. However the estimated cost for steam sterilization was low compared to MB. This cost included only fuel and labour and did not include the investment for the steamer and the soil equipment for negative pressure.

Table 3: Yield comparison of Methyl Bromide alternatives applied to strawberry during two cropping seasons

Selected alternatives	1998-1999	1999-2000
Control	754	636
Methyl bromide	891	801
Solarisation. (6wks)	810	790
Metam sodium+Solarisation. (4wks)	836	807
1,3 D+Solarization (4wks)	833	833
Negative Pressure Steam Soil Pasteurization	890	----

The calculation of economic return was based on the cost of each alternative, the yield and the export and local market price of strawberries during the production season. The alternatives increased total profit by 1 to 2%. However this small profit compared to the control was dependant on the export market. In fact, most of strawberry production is exported as fresh fruit to Europe until early April and as frozen fruit until the end of the season (June –July).

Table 4: Comparison of the economic return of methyl bromide alternatives in strawberry production

Selected alternatives	Net profit as % of the control
Control	----
Methyl bromide	+2%
Solarisation. (6wks)	+1%
Metam sodium+Solarisation. (4wks)	+2%
1,3 D+Solarization (4wks)	+1%
Negative Pressure Steam Soil Pasteurization	+2%

ALTERNATIVES - TECHNICAL BACKGROUND

Negative Pressure Steam Soil sterilization (NPSSS)

In farms dedicated to a very early production and intensified cropping system, planting occurred early September to produce and export in January. Soil preparations (cleaning from previous crop remains, plough, irrigation) prior to soil disinfestation was required in late August. Under these circumstances, the selected alternative had to take into account the short period available for soil disinfestations. To this end, steam sterilization was appropriate.

The conventional sheet steaming performance was limited in sandy soils. Appropriate temperatures (70°C) were obtained only in the first 10-20 cm of the soil profile. Meanwhile, Negative Pressure technique generated appropriate soil temperatures at 60 cm soil depth and complete control of nematodes, fungi and weeds was achieved.

In this technique, steam is introduced under steaming sheath and forced to enter the soil profile by a negative pressure. The negative pressure is created by a fan that sucks air out of the soil through buried perforated polypropylene pipes. This system requires a permanent installation of perforated pipes into the soil, at a depth of at last 60 cm to be protected from the plough. However, the technique needs an initial investment to install the negative pressure piping and the steam generators.

Solarization

The solarization period of six weeks, using a clear polyethylene plastic cover (40 µ), increased the soil temperature to 46°C in the first 10cm soil layer and to 38°C in the 30cm soil layer. These temperatures were 14°C higher than those observed in the control. These high temperature were observed over a 14 day period during August and early September. Under laboratory conditions, after a two week exposure to 40°C, the infection potential of *Meloidogyne javanica* larvae was completely eliminated, but hatching of eggs was drastically affected and not totally eliminated. Continuous hatching of eggs, even under high soil temperatures, permits early re-infestations which can originate from deep soil profiles with soil temperatures below 40°C which limits the effectiveness of solarisation applied alone (Eddaoudi and Ammati 1996).

Solarisation was combined with an organic amendment partially decomposed with an adequate C:N ratio > 11, equivalent biofumigation. The dosage of bio-fumigant varied from 70 to 140 tonnes/ha. It is recommended to place the biofumigation material in a layer at 10 to 20 cm from the soil surface, this layer is then covered with the soil, watered to start fermentation and usually covered with a plastic tarp.

Solarization combined with 1,3-D and metam sodium

Following 1,3 D soil injection and metam sodium application through the existing drip irrigation system, the soil was immediately covered with clear polyethylene film (40µ), brought to the field capacity for water and left under solarisation for 4 weeks instead of at least 6 weeks required for conventional solarization. Soil solarization combined with 1,3-D is highly recommended where only root-knot nematode is a major soil problem. Metam sodium is a poor nematicide but a good herbicide and fungicide.

The behavior of these fumigants in soil was studied under laboratory and field conditions. These chemicals undergo accelerated biodegradation after only one application (Bouzoubaa *et al.* 2001). Consequently, a reduced efficacy of both fumigants could be expected. However, elevated soil temperatures induced by soil soilarisation could eliminate the specific microflora generated by repeated application of these pesticides. There is no evidence of a negative interaction between 1,3-D and MS indicating that they could be applied simultaneously to ensure a good pest control (El Hadiri *et al.* in preparation).

The mobility and the persistence of these fumigants in the soil profiles, and their loss to the atmosphere, are summarized in Table 5. Maximum volatilization of 1,3-D reached 28% of the applied rate compared to only 9% of the metam sodium. Both fumigants 1,3-D and MITC were concentrated in the upper soil layers. Their degradation was very fast after 4 days had elapsed.

Table 5: Behavior of 1,3-D and MITC in undisturbed sandy soil columns

Chemical	Duration[2] (days)	Cumulated volatilization losses (%)	Extracted from soil (%)[3]	Degradation (%)
1,3-D	1	9.40	90.23	0
	2	8.48	93.83	0
	4	15.96	45.87	38.17
	11	28.69	15.47	55.84
MITC[1]	1	3.63	96.36	0
	2	4.55	78.99	16.45
	4	4.9	61.12	33.98
	11	9.19	27.55	63.26

[1]Methyle isothiocyanate, principal metabolite of metram sodium; [2]Days after application of fumigants (1,3 D and metam sodium); [3]Persistent quantity in soil profile.

CONCLUSIONS

The selected alternatives do not require any regulatory approval and are being investigated within an IPM programme under project MP/MOR/00/164.

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ALTERNATIVES TO METHYL BROMIDE IN STRAWBERRIES IN POLAND

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ABSTRACT

Strawberry production exceeded 200,000 tonnes in 2001 in Poland. Strawberries are normally produced in open fields as part of a crop rotation with cereals, seed rape, root crops, some legumes and potatoes. As a result of low prices for processing strawberries in the past two years, many growers are producing strawberries for the higher-priced, fresh market. The most suitable cultivars for this market are more susceptible to soilborne arthropod, fungal and nematode pathogens. Methyl bromide (MB) has never been used on commercial scale in Poland until recently when it was used for strawberry plant propagation at the request of Spanish importers of runner plantlets. Alternatives to MB include fumigants (Basamid, Telopik and Nemosol) and insecticides (Dursban and Basamid); and Integrated Fruit Production (IFP) that includes crop rotation, the use of healthy planting material, resistant or tolerant varieties, soil amendments and bioagents. IFP for strawberry fruit production could be the best alternative in Poland to eliminate MB and other soil fumigants. Soilless culture has a future in the production of planting material.

Keywords: Strawberry, soil-borne pathogenes, Methyl bromide (MB), alternatives, fumigants, integrated production, rotation.

INTRODUCTION

Strawberry production has had a long tradition and is of great importance to Poland. About 170,000 tones of strawberry fruits were produced yearly in 1999 and 2000, but production exceeded 200,000 tones in 2001. About 60% of the product was exported, mainly to Germany. While some fruit is sold fresh, the majority is frozen (about 75%) or processed. Frozen Polish strawberries account for about 21% of the world's supply.

Strawberries in Poland are normally produced in open fields as part of a crop rotation with cereals, seed rape, root crops, some legumes and potatoes. The main cultivar is Senga Sengana as it is the most suitable for processing and relatively tolerant of soilborne pathogens prevalent in Polish conditions. This variety is also frost resistant. The most common planting time is September and the first part of October or early spring, using usually fresh runner plantlets as frigo plantlets are still rarely used. Fields are maintained for several years, mainly 3-4 years, giving 2 or 3 crops in total.

In spite of low average yield, strawberry production was still more profitable than other agricultural crops, particularly on light sandy soil. As a result of low prices for processing strawberries in the past two years, many growers now produce of strawberries for the higher-priced, fresh market. Fruit produced for the fresh market requires more input and effort. The most suitable cultivars for the fresh market are more susceptible to soilborne pathogens which puts more pressure on growers to control soilborne pathogens.

MAIN SOILBORNE PESTS AND PATHOGENS

The main pathogens which occur in Poland that may attack strawberries in open field production are:

Arthropods: European cock chafer (*Melolontha melolontha*). Its larvae (white bugs) can be harmful pests to young plantations, particularly if located close to a forest; Wireworms, larvae of click beetles, particularly of common *Agriotes linealus*. They also can be harmful to young beds, especially if established after meadows and other uncultivated fields; and strawberry root weevil (*Othiorhynchus ovatus*) and some other related species that can be harmful to strawberries usually on light soil and particularly after a legume crop. The potential harmfulness of their larvae increase with the age of the strawberry beds.

Nematodes: Root-lesion nematode (*Pratylenchus penetrans*) is a problem for strawberries grown on light sandy soil as the feed on the roots and destroy the plants cortical tissue. It is the main cause of strawberry black root rot; Needle and dagger nematodes (*Longidorus* spp. and *Xiphinema* spp., respectively) are not only direct pests of strawberries due to their ability to stunt root growth, but they can also be vectors of some strawberry viruses.

Fungi: Fungal pathogens such as *Verticillium* spp. and *Phytopthora cactorum*, occur commonly in Poland and are particularly harmful to some cultivars, especially to those grown for fresh market fruit. *Phytophthora fragariae* and *Colletotrichum acutatum* are now in Poland as quarantine pathogens due to the possibility of their distribution with infected plantlets. They may be a problem in the propagation fields.

USE OF METHYL BROMIDE

Methyl bromide (MB) is one of the most effective soil fumigants but has never been used until recently on commercial scale in the open field production of strawberry fruit in Poland. Its lack of use was not only because growers had no tradition of using it but also because of its high cost in relation to other production costs and prices for fruit.

Recently, however, MB has been adopted in strawberry plant propagation on an area of about 68 hectares at the request of Spanish importers of runner plantlets. It is quite possible that other producers of runners plantlets would like to fumigate soil not only because of possible increase of runner production efficiency but also because of regulations which require transplanting material to be entirely free of some pathogens. However, considering the phase out MB in 2005, it appears very important to look for alternatives to MB for this use.

POSSIBLE ALTERNATIVE FUMIGANTS

Basamid GR (dazomet), generator of methyl isothiocyanate as the active ingredient, is a granular compound and therefore easy to apply. It can be applied on the soil surface and then mixed uniformly with the soil to a depth of at least 20 cm by mechanical means. Its effectiveness can be improved by irrigation, by rolling the soil surface or by using a plastic cover. The cost of its application is about 60% of the cost of applying MB. Its effectiveness in strawberry runner production has been confirmed in several field experiments in Poland by Ślusarski and Peter (unpublished data).

Nemosol (metan-sodium) is a liquid formulation and, similar to Basamid, generates methyl isothiocyanate as the active ingredient. Its efficacy in strawberry propagation appeared, however, to be much weaker than Basamid.

Telopik consists of 67% of 1,3–dichloropropene and 33% of chloropicrin. Its efficacy can by comparable to that of Basamid in certain conditions. It appeared effective in controlling soil-born pathogens, particularly if combined with biocontrol agents, but it was not effective against weeds.

Both Nemosol and Telopik, being liquid preparations, require special equipment for their application. The cost of their application is comparable to that of MB. Basamid and Telopik could be expected to replace MB in the near future in Poland in strawberry plant propagation and to less degree in fruit production.

INSECTICIDES

Dursban (chlorpyrifos) and Basudin (diazinon) are recommended in Poland for control of cockchafer larvae, wireworms and strawberry root weevil. Dursban is recommended usually before planting, while Basudin can be also used locally on existing plantations. They are, however, not effective against nematodes and fungal pathogens and cannot replace fumigants for these purposes. Therefore, other mainly preventive methods have to be used instead.

NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE

Integrated fruit production

Integrated fruit production (IFP) is a technology in which pest and disease control is based on monitoring, establishment of monitoring levels and combination of strategies and tactics that seek to prevent pest and disease problems in an economically and environmentally sound manner. The programme combines biological, cultural, physical, mechanical and chemical (with selective compounds) methods. Therefore, IFP for strawberry fruit production could be the best alternative in Poland to eliminate MB and other soil fumigants.

IFP in strawberries started several years ago and is continued by 6 groups of producers operating in 2001 on about 240 ha (Anon 2000).

Rotation

Rotation means cultivation of one or more crops that are non-hosts or less-suitable hosts to pests and diseases, or those crops that trap or are antagonistic to pests and diseases, which would reduce all target soil pathogens and be economic to implement.

Rotation has been used in strawberry production in Poland for many years, although selection of crops and intervals between successive strawberry planting were not always appropriate. Rotation is now an integral part of IFP. Therefore, in the farms operating IFP the crops for rotation are carefully selected. The most effective rotation crops are cereals, seed rape, beets and some annual legumes, alone or in mixture with cereals. Potato, tomato, cucumber and pepper are not effective rotation crops. The crops that directly precedes strawberries are always cereals or mustard; the last one possesses sanitation properties and can be also used as a green manure after chopping and ploughing.

Tagetes spp. appeared to be very effective against root parasitic nematodes. Therefore, it was recommended as a preceding crop to strawberries grown in light soil in which nematodes commonly occurred. *Tagetes* spp. can reduce nematode populations to non-harmful levels after about four months and then they can also be used, after chopping and ploughing, as green manure.

HEALTHY PLANTING MATERIAL

Some of the soil-borne strawberry pathogens, particularly fungal ones, such as *Verticillium* spp. *Phytophthora* spp. and *Colletotrichum* spp., can be spread by infected runner plantlets. Therefore, healthy planting material is one of the most important ways of avoiding losses due to these pathogens and is a standard requirement in IFP.

Resistant varieties

The susceptibility of strawberry cultivars to soilborne pathogens, especially to fungal ones, differs. Senga Sengana is weakly susceptible to root-pathogenic fungi, while Elsanta is very susceptible. Senga Sengana is also less susceptible to root-lesion nematode than other varieties and thus also to black root rot disease. Therefore, more attention should be given to this point in breeding new varieties which is conducted in Poland. It will be, however, not easily to breed new varieties resistant or tolerant to all or most soilborne pathogens.

Soil amendments

Organic amendments can reduce some pathogenic fungi and suppress other ones and some nematodes when added into soil (Peter 2001). Mainly animal and green manures are commonly used in open field production of strawberries in Poland. The animal manure is recommended usually directly preceding strawberries, although it has also been used shortly before planting strawberries. This is especially useful treatment in small farms common in Poland.

Soilless culture

This method involves growing plants on special substratess such as rockwool, glasswool, tuff stone, peat, polyurethane, pine bark and others, thus avoiding infection with soilborne pathogens. Soilless culture has not been used until recently for commercial strawberry production in Poland. It has, however, been recently used on limited scale and with a good results for producing strawberry runners. Soilless culture under plastic tunnels or in greenhouses can be an effective way for producing strawberry fruit for the fresh market.

Biological methods

Biological methods consists of using non-pathogenic organisms that either compete for space and nutrients or are antagonistic to pathogens. Non-pathogenic organisms should, however, be present around plant roots during their susceptible period.

The entomopathogenic nematodes are known to control some insect pests and have been used until recently only in home gardens to control strawberry root weevils (*Othiorhynchus* spp.). The use of these nematodes for the biological control of soilborne pests in open field production can be a method for the future. Finding races easy to rear is being studied in Poland as this is a requirement for further development of this method.

The other biocontrol agents, which can be used effectively against some soilborne pathogens, are some saprophytic soil fungi of which *Trichoderma viride* and *Pseudomonas inflorescens* appeared to be quite effective (Ślusarski and Peter unpublished). The best effect can be obtained when fungi are used together with other treatments, for example with Basamid and Telopik or organic amendments. It is possible in this way to decrease dosages of the above mentioned fumigants without decreasing the efficacy of the treatment. However, an efficient technology for producing fungal bioagents on a commercial scale is required.

CONCLUSIONS

Effective methods for protecting strawberries from soilborne pathogens is required for strawberry growing in Poland to remain profitable in the future. Basamid and Telopik are the most promising and can replace MB, particularly when combined with bioagents. However, both fumigants are still not available to small fruit producers because of their costs. They are also not acceptable in IFP. Therefore, the main attention should be given to non-chemical methods such as rotation, healthy planting material, resistant or tolerant varieties, organic amendments and possibly fungus bioagents, particularly when combined with organic amendments. There is also justified to use soilless culture for producing planting material.

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THE USE OF SUBSTRATES FOR STRAWBERRY PRODUCTION IN SPAIN

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ABSTRACT

The cultivated strawberry (*Fragaria x ananassa* Duch.) is one of the most important crops in Huelva (Spain). Huelva is leader in the organization and pioneering of integrated production and research for strawberry production. The strawberry industry of Huelva is the most important in the European market. *Phytophthora* spp. and *Verticillium* spp. are two of the most wide-spread and destructive diseases of strawberry that occur in practically all zones of commercial strawberry production. Methyl bromide (MB) is used largely to control these diseases. Banning MB has acted as a catalyst for the ongoing development of new and modified technologies such as soilless growing systems. Soilless culture aims to achieve a more sustainable, efficient and environmentally-friendly growing system for strawberries using as the substrate slabs of peat, coconut fiber, grape bagasse compost or composted cork combined with slow sand filtration for disinfection of the recirculated nutrient solution.

Keywords: methyl bromide, strawberry, closed soilless growing systems, slow sand filtration, disinfection, substrates, biological control, environmental control, *Phytophthora cactorum, Verticillium dahliae.*

INTRODUCTION

Cultivated strawberry (*Fragaria x ananassa* Dutch.) is the result of the interspecific hybridisation between two American species *F. chiloensi* (L) Duch. and *F. virginiana* Duch., that took place in Europe in the 18th century. This hybrid is the most widely grown species, although *F. vesca* L. and *F. moschata* Duch. are also grown on a commercial scale, but with much less acreage. Strawberry is cultivated under a wide range of conditions of photoperiod and temperature, from subtropical climates to relatively cold climates (Darrow 1966).

Although strawberries are grown in all regions in Spain, production from the province of Huelva in the region of Andalucía totally dominates (Lopez-Aranda 1995), accounting for 50% of total European production. Huelva has pioneered the production organization and integrated management of strawberries. Economically, strawberry production accounts for 60% (€ 252.4 million) of the income from agriculture in the province.

In 1994/95, the "Camarosa" variety from University of California was first planted in Huelva. In only four years, this variety reached 80% of total strawberry acreage (Lopez-Aranda 1998). The crop system is producuced annually in raised beds covered with black polyethylene, using fresh plants from high altitude nurseries that are autumn-planted with short-day varieties. Microtunnels (about 90% of the acreage) and macrotunnels are used to protect the crop. The most modern techniques of cultivation are used: localised irrigation, fertigation, optimum density of plantation, and other technieques (Lopez-Aranda *et al.* 1996,1997).

Strawberries are grown in the same place year after year (with no rotation) with varieties that are extremely susceptible to *Phytophthora* spp. and *Veticillium* spp.. Soil disinfection has become essential for controlling soilborne pathogens. The most widely used product is methyl bromide (MB) (Lopez-Aranda, 1998, 1999), although its association with ozone layer depletion has resulted in it being banned under the Montreal Protocol. A national research project (with financing from INIA, SC97-130) is searching for alternatives to MB.

Soilless growing systems are an alternative for soil fumigation. De Barro and Edwars (1995) showed that strawberry production without MB was possible using peat as the substrate. They emphasized the following advantages:

1. Soil disinfection was not necessary and can be avoided;

2. Soilless system have hanging plants and therefore neither the plants nor the fruit are in contact with the soil;
3. Conditions around the plant are much drier so *Botrytis* is not a problem;
4. Integrated pest management is much more effective;
5. Collection of the fruit is very comfortable as the fruit remains at a comfortable height for picking;
6. Residues are minimised as the substrate can be reused, or used as organic amendment for soil, and the plastic bags can be recycled; and
7. In a closed soilless growing system, contamination of soil and surface water is reduced, but 100% efficiency in water and fertilisers use has not been achieved yet (Van Os 1999a).

SOILLESS GROWING SYSTEMS

Alarcon *et al.* (1998) clarified that, in Spain, almost all plots with soilless crop are under greenhouses and are nowadays open systems in which the water solution is lost. Soilless systems allow mineral nutrition and water contribution adjusted to the momentary needs of the plant. Drainage may be necessary to avoid excessive salt concentrations (total or specific of a determined ion) in the root environment. Drainage can remove between 20 to 40% of the nutrient solution and, in extreme cases, when the electric conductivity of the water is between 3 to 5 dS/m, it can be of 70%. Lixiviates are thrown to the soil and allowed to percolate, or they can be channelled out of the greenhouse for later release. In water and fertiliser use, the sustainability of the open systems is questionable.

Soilless crop in substrates were originally open systems with lost solution, but later other systems like hydroponics or subirrigation were designed as closed systems. Nevertheless, due to the ever growing concerns over potential to the environment, open systems are being adapted so that each day drainage waters are re-used because:

1. Water is scarce in the main horticultural production areas making water management obligatory;
2. Fertilisers can be used with maximum efficiency in closed soilless systems;
3. A closed system can be maintained for many chemicals applied to the crop, like fungicides, insecticides, disinfectants and humic acids; and
4. Aquafer contamination due mainly to accumulation of nitrates, phosphates and insecticides can be avoided.

Open systems produce important volumes of lixiviates that are thrown out with high contaminant risk of the environment. In closed soilless systems, almost 100% reduction of environmental contamination can be achieved and important amounts of water and fertilisers can be saved. Closed soilless systems can conserve 30% of the water and 40% of the fertiliser use compared to open soilless systems (Van Os, 1999b).

Legislation in force in certain countries of Europe mandate, or is about to mandate, recirculation of the irrigation water. It is not surprising that countries with a big tradition in soilless crops like the Netherlands was first to apply water recirculation. In 1989, The Netherlands created a specific inspectorate under “The National Environment Policy Plan” that now has the general objective of watching over the sustainable development of their horticulture sector. In Holland, closed systems were about 20% of soilless crops in 1996, and the forecast for year 2000 was that all acreage of open soilless systems were to be converted to closed systems (Van Os 1999b).

In Spain, crops with recirculating nutrient solution have been limited to research experiments and were based on NFT (Nutrient Film Technique), although today there are recirculating systems at the commercial stage of NFT. More recently, a new variant called NGS (New Growing Systems) has been developed. The first trials on closed systems were reported by Garcia *et al.* (1998) who concluded that these techniques were commercially feasible (Urrestarazu *et al.* 1998).

The addition of a recirculating system in a soilless crop means an added cost compared to an open system. Therefore, the selection of the most adequate equipment and methods will determine the economic viability of the crop. In closed soilless systems the lixiviates must be reintroduced into the fertilisation circuit, thus it is necessary to install collectors that allow the recovery of the lixiviates at the end of each line, or bench of the crop. Lixiviates have two basic characteristics (Marfá, 2000):

1. The ionic composition is not equal to the composition of the originally nutrient solution, although usually it is similar; and
2. They incorporate solids in suspension, solutes exuded by the crop roots and microorganisms that may be pathogens and are propagate by the whole operation.

Pathogen microorganisms that are best transmitted in the recirculating soilless crops are *Phytium, Phytophthora, Verticillium, Fusarium, Xanthomonas, Erwinia,* etc., virus and nematodes. Lixiviates must be: filtered, disinfected and reintroduced into the closed circuit, correcting the ionic composition (when possible), and in an automatic process. The main method of disinfectation of lixiviates are: Heat treatment, ozone and hydrogen peroxide treatment, ultraviolet radiation, membrane filtration, chlorination or iodination, and slow sand filtration (biologic filter). Of these six methods, slow sand filtration is the only biologic disinfection method in which nutrient solution is not sterilized and thus the development of certain microflora can occur and can fulfil an important role in disease suppression (Van Os, 1999b).

SUBSTRATES

Strawberry crop in soilless systems began in Huelva in 1997 and today there are several alternatives of open systems. The ideal system is the one based on hanging trays at an unique level (they could also be leaning on): Raising from the soil: 1,5 m.; distance between lines: 0,5 -1 m. and planting density: 11 - 22 pl/m^2. The fruit yields obtained in 98/99 and 99/00 were of 716 and 621 grammes per plant (g/pl) respectively, considering only first quality fruit and crop density of 90,000 plants per ha (pl/ha) (Del Toro 2001).

Another possibility is the pyramid layout: Distance between pyramids: 2-3 m; number of levels: 5 and planting density: 10 pl/m; which means 33-45 pl/m^2. With this system, the yields obtained in 00/01 were 180 g/pl with rockwool and 300 g/pl with coconut fibre, which means 8 and 10 kg/m^2 respectively (Caço, J.C., 2001). Today only 2 level pyramids are recommended.

Substrates that are usually used in strawberry crop are: Peat, coconut fibre, rockwool, Perlite and alternative substrates as grape bagasse or composted cork. Peat is commonly used as substrate in strawberry soilless growing system, but is a non renewable source. Coconut fibre can contain rather large amounts of Na, Cl and K. These have to be washed out of the substrate before planting. Peat provides a better water buffer than coconut fibre or rockwool. Re-use of peat is not recommended, however, but re-use of coconut fibre is possible (Evenhuis *et al.* 2001).

Practically any substrate can be used to grow strawberries with soilless systems, provided that it is adequately managed. There are substrates that require more experience, thus it is usually recommended substrates that are easy to use and produce good yields such as peat and coconut fibre and with a volume of 10-25 l/m.

The elimination of substrates used in soilless systems at the end of their life means, in some cases, a problem. For example, rockwool is not biodegradable and the residues are noxious to human health (Benoit 1990). This is not a problem with the residues of organic substrates (peat) that are biodegradable and can be incorporated to the soil as organic amendments (Marfa 2000).

Nevertheless, peat is not a renewable resource, so alternative substrates must be found that are renewable and improve the sustainability of the soilless system. Thus a search has begun for local materials in many places of the world that could be used as substrates, with the added value of reducing production costs. There are already limitations on how much peat can be extracted due to policies in place that protect the environment in peat-producing countries. Peat reservoirs are now known to be important reservoirs of carbon dioxide (Abad, 1991). In this context, agro-industrial residues have an special importance (Raviv *et al.* 1986).

An outstanding characteristic of substrates made from compost is their ability to suppress the production of the most important soilborne fungal diseases of plants (Hoitink *et al.* 1996). This property, although widely documented in the literature, is not exploited in practice in Spain because it has not been analysed in our composts and for our pathogen systems. From all the residues easily available in Spain grape bagasse stands out due to its good characteristics as a horticultural substrate once it has been composted (Kostov *et al.* 1996). Its ability to suppress certain pathogen systems in which soilborne fungi pathogens are involved is proven (Maldelbaum *et al.* 1988)

In a sustainable soilless crop system, the materials and substrates must inexpensive with a life time of 3-4 years and with constant physical properties during their life. They must be also safe and be recycled by the supplier (Van Os, 1999b). Our results (although provisional) show the viability of composted grape bagasse and composted cork as possible alternative substrates. Nevertheless, there are micro-nutrient deficiencies that are mainly iron-related that can be solved with the use of adequate chelates.

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ALTERNATIVES TO METHYL BROMIDE FOR DURABLES AND TIMBER

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ABSTRACT

Methyl bromide (MB) has a number of desirable features as a fumigant for durable commodities and timber including a rapid speed of treatment, low infrastructure requirements, recognition by quarantine authorities, broad registration for use, good penetrant ability, and rapid airing after exposure. There is, however, a range of existing and potential alternatives to MB which, alone or in combination, could be adopted to replace the few remaining non-QPS uses of MB. The strengths and weaknesses of each alternative are discussed in the paper.

Change inevitably brings some costs and difficulties as new techniques are learned and adapted to fit the prevailing commercial and regulatory environments. The change may be minor if the alternative rapid-acting fumigants (e.g. sulfuryl fluoride) become registered on foodstuffs and available soon. If non-chemical techniques, such as heating are adopted, there may be substantial investment and changes in procedure needed. However there is also an opportunity as MB is not an ideal fumigant. Adoption of alternative pest management systems may end up providing better and cheaper processes for disinfestation and protection of durables and timber.

Keywords: Methyl bromide, alternatives, heat, phosphine, intergrated pest management, quarantine, pre-shipment, durables, timber

INTRODUCTION

In 1998, the Methyl Bromide Technical Options Committee (MBTOC) estimated 12% of global methyl bromide (MB) production was used as a fumigant on durable commodities, including timber and wooden products. Durables are commodities with a low moisture content that, in the absence of pests, typically can be stored for long periods at normal temperatures without deterioration. Durables include a number of foodstuffs, such as grains, oilseeds, dried fruit and nuts, and cereal-based milled products. Dry non-food commodities such as timber, wooden packaging and cotton as also classed as durables.

Many durables in trade and storage can be attacked by pests, including insects, mites and fungi, causing loss of quality and value. They may also carry pests and diseases that may be a threat to agriculture, health or the environment. There are a wide variety of measures that can be taken to manage these pests so that the damage they cause or risk that they pose is acceptable. Fumigation with methyl bromide is one such measure.

Most current uses of MB on durables, worldwide, are highly specialised. In a few instances, in a few industries and countries, MB use has been in routine use for decades as a well-developed system with a good record of successful use. In such cases, prior to MB phaseout because of its ozone-depleting properties, there was little reason to adopt alternative practices. An example of a widespread specialised use is the fumigation of durables and export timber for quarantine purposes. Fumigation of bagged grain in store in parts of Africa or stored dried vine fruit (sultanas) in Australia are examples of well established, ‘traditional’ use.

Alternatives to MB need to be assessed against the properties of MB as a fumigant and its place in the general management of the quality of durables and timber. MB has a number of desirable features as a fumigant including a rapid speed of treatment, low infrastructure requirements, recognition by quarantine authorities, broad registration for use, good penetrant ability, and rapid airing after exposure. When considering alternatives, these properties need to be viewed against a background of MB as a highly toxic, odourless gas with a substantial ozone-depleting potential and adverse effects on a number of durables, particularly loss of viability, quality changes, taint and residues.

Most remaining uses of MB on durables are as a control agent against insects, mites and vertebrate pests. However MB also has activity against nematodes, snails and fungi, although at much higher dosages (*ct*-products) for these organisms than against insects (typically *ct*-products exceeding 5000 g h m^{-3}, compared with about 200 g h m^{-3} for insects). At very high dosages, MB also can devitalise seeds. Alternatives to these other uses are more restricted than for those for control of insect, mite and vertebrate pests.

MB has a particular application in quarantine and preshipment (QPS) treatments. It has a long and successful history as a quarantine fumigant for durables and timber in trade. In many situations it is the only treatment approved by national quarantine authorities. There is a large body of data on responses of pests to MB to support its use, it is relatively noncorrosive, and it can be applied easily to shipping containers or to bagged, palleted or bulk commodities 'under sheets'. The treatments may be applied before shipment as a precaution against particular quarantine pests or on receival, where there is a detection of a quarantine pest or risk that one such pest is present. These treatments come under a number of international and national agreements and regulations, including particularly the IPPC and various national quarantine regulations.

MB fumigation can also be the treatment of choice in pre-shipment situations where infrastructure limitations and need for a rapid treatment make phosphine fumigation, the main current alternative, a less convenient option.

The challenge now is to develop, register and deploy alternatives to non-QPS uses of MB before the 2005 phaseout date in developed countries, and to meet agreed freeze in consumption and partial phaseout in developing (Article 5(1)) countries. There is also a need to work out ways of avoiding MB for QPS to avoid disruption to trade in the event of restrictions being placed on this emissive MB use. The EC has already curtailed MB use in QPS under regulation EC2037/00 in order to restrict QPS use of MB and assist in protecting the ozone layer. Many see restriction of QPS MB as inevitable, though the timeframe for this is not clear.

ALTERNATIVES

MBTOC has produced two Assessment Reports (MBTOC 1995, 1998) that detail alternatives to MB for durable and timber uses. There are also updates to these reports (TEAP 1999, 2000, 2001) and a new full assessment is in preparation (scheduled for publication in late 2002). Despite the unique properties of MB, these documents show that there are a wide range of potential alternatives to MB use for durables, with a more restricted choice for timber and timber packaging.

A particular difficulty encountered when discussing and assessing MB alternatives is the lack of definition of what existing MB treatments actually achieve in practice, and what they are expected to achieve in terms of level of pest control or kill. The level of tolerance of infestation varies widely with each commercial situation, pest(s) present or possibly present, and even different national standards. Some quarantine treatments aim for Probit 9 level of kill of all pest stages present, while, at the other extreme, treatments may be carried out to kill off easily visible infestation or even just reduce the infestation level somewhat. There is a wide variation in the practise of MB fumigation worldwide, with some treatments being of questionable utility and effectiveness. Treatments are often applied as routine prophylactic measures or commercial requirements without determining whether a treatment is actually necessary. For the purposes of this presentation, a process is considered to be an alternative if it achieves the same (undefined) success as MB, as typically applied.

Generally, there are technically feasible alternatives for almost all non-QPS uses of MB on durables. When considering alternatives to MB, it is clear that the alternatives are situation specific. Development of a single, direct replacement for MB is most unlikely. Selection of the best alternative will have to be made on a case-by-case basis.

For non-QPS MB applications, MBTOC (1998) found only very few instances for durables where there was no technically effective alternative. These were:

- Disinfestation of fresh chestnuts;
- Disinfestation of fresh walnuts for immediate sale;
- Elimination of seed-borne nematodes in some seeds for planting; and
- Control of organophosphate-resistant cheese mites in traditional stores.

World use of MB for these applications was considered by MBTOC unlikely to exceed 50 tonnes per annum and there good progress was reported in developing alternatives.

Some alternatives given below may be more expensive in material cost, or overall, than MB while achieving the same result. Some require capital investment (e.g. heat treatments), but may be competitive with MB at current prices in terms of running cost. There may also be one-off costs associated with the transition from MB. However, many alternatives also avoid the onerous and extensive restrictions associated with fumigations using toxic gases such as MB, and thus turn out to be more appropriate than MB in the long term.

Alternatives for durables and timber are discussed below by technology, not by commodity or situation. Many alternatives are generic, with applicability to many different durables with only minor changes in technique to cope with different pest complexes and situation. Where reference is sought to alternative treatments for a particular commodity, readers are referred to the postharvest section of the TEAP/MBTOC index of alternatives to MB (www.teap.org). This index provides page references to discussion of particular alternative/commodity combinations. The index is to be updated periodically to incorporate progress in development of alternatives.

Alternatives are grouped below under the following categories: Alternative fumigants (in-kind alternatives); and Non-fumigant alternatives (not in-kind alternatives). The latter is a large category – essentially it is all of the non-fumigant technology of stored product protection – and only general approaches as alternatives to MB are given. Alternatives discussed in this paper are those that are available in at least some developed countries now, or look likely to gain registration in some developed countries by the date of MB phaseout (1 January 2005).

Tables 1, 2 and 3 list in-kind alternatives for durables, not in-kind alternatives for durables and alternatives for timber and wooden products respectively. A brief summary of the strengths and weaknesses of particular alternatives is also given. For more detailed discussion the MBTOC Assessment Reports (1995, 1998) should be consulted.

Tables 1, 2 and 3 list single MB alternatives. Many of these options are best applied in combination or sequentially as part of a rational system of protection of durables and timber. For instance, a phosphine fumigation may be followed by cooling to protect stored grain from reinfestation and subsequent need for further treatment. Such a combination may avoid the need for a MB fumigation later in the life of the stored grain prior to export or end use.

Table 1: In-kind alternatives to MB for durables – principal strengths and weaknesses.

Fumigant	Weaknesses	Strengths
Methyl bromide	Ozone depletor, residues, taint	Range of registration/acceptance, reputation
Carbon bisulphide	Flammability, registration, residues	
Carbon dioxide (high pressure)	Infrastructure needs, small scale	Rapid, low toxicity gas
Carbonyl sulphide	Registration	Naturally occurring
Controlled atmospheres (atmospheric pressure)	Slow acting	May not need registration, less regulation
Controlled atmospheres (vacuum)	Slow acting	Low technology, may not need registration
Dichlorvos	Poor penetration, residues, resistance	Useable in unsealed enclosures
Ethyl formate	Highly sorbed, registration	Rapid
Ethylene oxide	Carcinogenic, flammable, infrastructure needs, residues	Sterilant
Hydrogen cyanide	Reputation, unstable in storage, highly sorbed	Very rapid
Phosphine (cylinder gas)	Flammability, corrosiveness, poor action at low temperatures, slow, resistance	Excellent penetration
Phosphine (phosphide	Flammability, corrosiveness, poor	Excellent penetration, low

Fumigant	Weaknesses	Strengths
formulations)	action at low temperatures, slow, resistance, tablet residues	technology, cheap, broad range of registration
Propylene oxide	Infrastructure needs, flammable, registration, highly sorbed	Sterilant
Sulfuryl fluoride	Registration, low effectiveness against egg stage	Good penetration, little sorption

Table 2: Not in-kind alternatives to MB for durables – principal strengths and weaknesses

Process	Weaknesses	Strengths
Integrated Pest Management/Integrated Commodity Management	Can be complex to operate	Avoids unnecessary treatments
Biologicals	Registration, often too specific, live material remains present	
Cold treatment (down to 4°C)	Not rapidly insecticidal	Long term protection, no registration required, no toxic chemicals
Cold treatments (below –15°C)	Not feasible on large scale	Rapidly insecticidal
Heat treatment	Infrastructure requirements for large scale use	Rapid, residue free
Inert dusts	Not active at high humidity, acceptance and product quality, slow acting	Long term protection, low technology process
Irradiation	Public acceptance, infrastructure required, product quality, live, but sterile pests can remain	Active against all pests
Pest exclusion/physical removal/sanitation		Simple process
Pesticides of low volatility (e.g. organophosphates, pyrethroids)	Market and regulatory acceptance, slow, resistance, residues	Low technology process, long term protection

Table 3: Alternatives to MB for timber and timber products

Process	Weaknesses	Strengths
Methyl bromide	Ozone depletor, not very effective against some fungi, does not penetrate wet timber	Low infrastructure needs
Debarking	Not effective on pests in wood, not all timber easily debarked	
Drying	Infrastructure needed, not applicable to whole logs, does not control all pests	
Heat	Infrastructure needed	Can be used on wet timber, can control fungi
Immersion	Requires extensive holding areas, applicable to logs only	
Phosphine	Slow, not active at low temperatures, little fungal control	
Sulfuryl fluoride	Not very effective against egg stages	

CONSTRAINTS TO ADOPTION OF ALTERNATIVES

Registration constraints are a particularly difficult issue in the context of MB alternatives. MB is used on a diverse range of durable foodstuffs. Any new chemical process, including fumigants, faces an expensive, complex and protracted assessment if it is to be registered for use. The total non-QPS MB market on durables is small and fragmented, restricting commercial development of new products. Nevertheless there are several fumigants that are in the process of registration, either to extend their current registrations (e.g. sulfuryl fluoride) or to gain new registration (e.g. carbonyl sulphide).

Development of non-MB quarantine treatments is particularly problematic. Not only do most specific usages consume little tonnage of MB, giving a very small market base, but also new quarantine treatments require extensive bilateral trials and negotiation for acceptance. MB treatment of export timber is one of the few quarantine applications of MB that consume large quantities of MB (worldwide, several thousand tonnes).

One of the main features of MB as a fumigant that make it desirable commercially is its speed of action compared with its principal competitor, phosphine, for protection/disinfestation of durables. MB exposure periods are typically 24h or less for a high level of kill of insect pests, with some pests requiring a 48h exposure. In contrast, phosphine requires several days even at 25°C to achieve the same level of control.

In-transit fumigation of durables with phosphine in ships, or phosphine or carbon dioxide in containers, appears to overcome the lack of speed-of-action of alternatives in the export trade, provided the ships or containers are well sealed and with appropriate safety precautions (see TEAP 2000).

CONCLUSIONS

There is a range of existing and potential alternatives to MB for durables and timber. The challenge now is which of these, alone or in combination, should be adopted to replace the few remaining non-QPS uses of MB. Already MB uses that a few years ago that were held to be irreplaceable have now been substituted with alternatives. For instance the disinfestation of Californian walnuts in storage, formerly a significant MB use, is now largely carried out using cylinderised phosphine.

Change inevitably brings some costs and difficulties as new techniques are learned and adapted to fit the prevailing commercial and regulatory environments. The change may be minor if the alternative rapid-acting fumigants (e.g. sulfuryl fluoride) become registered on foodstuffs and available soon. If non-chemical techniques, such as heating are adopted, there may be substantial investment and changes in procedure needed. However there is also an opportunity. MB is not an ideal fumigant. Adoption of alternative pest management systems may end up providing better and cheaper processes for disinfestation and protection of durables and timber.

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ALTERNATIVES TO METHYL BROMIDE FOR DISINFESTATION OF STRUCTURES AND FOOD FACILITIES

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ABSTRACT

Fumigation of milling facilities with phosphine has been difficult in the past due to its corrosive effect on copper, brass and other precious metals contained in electrical, computer and other valuable equipment. A recently registered formulation of phosphine called Eco_2Fume^{TM}, when combined with specific fumigation practices, now makes fumigation with phosphine possible. A large milling facility was fumigated in the United States using low concentrations of phosphine as Eco_2Fume^{TM} combined 3-5% CO_2 and elevated temperatures. The fumigation time was 24 hours. 100% of all life stages of the confused flour beetle were killed by the treatment and no beetles were caught in traps in the following two weeks after fumigation. The cost of the fumigation was comparable to MB. Other companies have adopted this disinfestation method when disinfestation is required. Eco_2Fume^{TM} fumigation is becoming more widely used as a replacement for the ozone depleting fumigant methyl bromide.

Keywords: New phosphine formulation, carbon dioxide, heat combined with fumigant

INTRODUCTION

With methyl bromide (MB) due to be phased out by 2005, the milling industry is under intense pressure to find a safe, viable, legal, and cost-effective substitute for structural fumigation. The Pillsbury Co. has been leading efforts to find such a substitute. In December 1997, the company's board of directors decided to stop the further use of MB in company facilities. Instead, the company has implemented an integrated pest management (IPM) program combining proper sanitary design of equipment and buildings, detailed sanitation procedures, good manufacturing practices, targeted use of labeled pesticides, detailed inspections, and heat treatments. None of these are cure-alls in themselves.

One alternative, phosphine, is well known as an effective treatment against stored product insects. However, traditionally, it has not been used for structural fumigation because of concerns over phosphine's potential to corrode milling equipment. Metals such as copper or brass, precious metals such as gold or silver, small electric motors, smoke detectors, brass sprinkler heads, batteries and battery chargers, fork lifts, temperature monitoring equipment, switching gears, communication devices, computers, calculators, and other electrical equipment may be damaged by exposure to high levels of phosphine. The fumigant also will react to certain metallic salts, which are contained in sensitive items such as photographic film and some inorganic pigments.

FUMIGANT

A new phosphine/ CO_2-based product called Eco_2Fume^{TM} phosphine fumigant has been able to replace traditional phosphine fumigation with tablets. Eco_2Fume^{TM} features a relatively low concentration of phosphine that is monitored strictly to help manage corrosion concerns. Pillsbury set out to test this product in an actual fumigation at its flour mill/warehouse complex in Hillsdale, MI, USA in May 2001 (there was also a fumigation in October 2000).

ECO_2Fume^{TM}, which was granted a label in August 2000 by the Environmental Protection Agency for structural fumigation in food plants, is a blend of 98% carbon dioxide (CO_2) and 2% phosphine, shipped in 205-lb. high-pressure cylinders. Developed in the early 1990s in Australia where more than 12 million metric tons of wheat are fumigated annually, Eco_2Fume^{TM} is manufactured and marketed worldwide by Cytec Industries Inc., West Paterson, NJ (1-973-357-3100/ www.cytec. com).

The Pillsbury facility was the first flour mill in the United States to be fumigated using a patented method combining Eco_2Fume^{TM} with heat and additional CO_2. This patent is held by Fumigation Service & Supply (FSS), which performed the actual fumigation with guidance from Pillsbury personnel. In order to use Eco_2Fume^{TM}, the user must not only be a certified applicator but also must attend and pass Cytec's product stewardship programme.

METHOD

The fumigation method used in May combined three elements:

1. A modified atmosphere containing 2% to 5% CO_2 by volume. Pest insects breathe through abdominal openings called "spiracles." High levels of CO_2 in the atmosphere cause these spiracles to remain in an open position in order to obtain more oxygen, thus allowing more phosphine to enter the insect.
2. Temperatures inside the building of 30.6°C to 35°C, which cause the insects to breathe faster, also increasing their intake of phosphine. (Note: this is a much lower temperature range than used in unsupplemented heat treatments. A straight heat treatment normally requires a temperature of about 54°C).
3. A low level of phosphine released from the Eco_2Fume^{TM} cylinders.

FSS supplied the Eco_2Fume^{TM} and technical help for the fumigation and served as the fumigator of record. In addition, 15 tons of CO_2 were obtained from Airgas Inc., Radnor, PA (1 610-687-5253/www.airgas. com). The work was done over a weekend, when the plant was shut down.

Two days prior to fumigation, employees were instructed to keep windows and doors closed as much as possible to aid in heating the building. Outdoor temperatures were about 26°C during the day and about 15 °C at night.One day before the fumigation, crews began to pre-seal the building, with special attention to windows, unused doors, window and exhaust fans, roof fans, and other exterior openings that could be sealed without affecting day-to-day operations. Steam heaters were used to raise indoor temperatures. By the day of the fumigation, indoor temperatures hovered around about 32°C.

Before the fumigation began, local emergency personnel were notified, including fire, police, the hospital emergency room, and county emergency 911 central dispatch personnel. All of these were provided with material safety data sheets for CO_2 and Eco_2Fume^{TM}, the Eco_2Fume^{TM} label, and emergency first aid information.

On fumigation day, early morning temperatures outside were about 4°C, with daytime highs about 21°C. That night, the temperature dropped to around 10°C, with calm winds. Nevertheless, interior temperatures remained about 32°C.

Note: Before fumigation, it's important to locate heat sinks inside a milling facility. These areas may be difficult to seal properly for heating. These locations should be cleaned thoroughly and fogged with an appropriately labeled pesticide such as DDVP (Vapona) or esfenvalerate (Conquer). These materials must *always* be used according to label instructions. To check the efficacy of the fumigation, test insect samples were placed both inside the fumigated area and outside the area.

For this test, FSS supplied samples of confused flour beetle, including 25 adult cages, 10 larvae cages, and 10 egg cages. One case of each was selected at random and kept outside the fumigated area as controls. Care was taken to place at least some cages in areas considered "difficult" for the gas to reach.

Before the fumigation proceeded, a final walk-through was conducted to make sure that all non-fumigation personnel were gone, sealing was complete, insect cages were placed, fumigation materials were on hand, equipment and raw materials were removed or protected as needed, and warning placards were in place.

After the walk-through, the Airgas tanker arrived. CO_2 was introduced into the building at 09:00 hours Saturday. After the required levels of 3% to 5% CO_2 levels were reached, Eco_2Fume^{TM} was introduced at 12:30 hours Saturday. The fumigation was completed at 12:30 hours Sunday. To detect any phosphine leakage from the plant, Plant Sanitarian Ernest Ellenwood took exterior air readings at 15:30 hours and 20:00 hours Saturday and 07:00 hours Sunday.

RESULTS

After the fumigation was completed, FSS personnel, wearing appropriate personnel protective equipment, entered the building and began aerating it. Sealing materials were removed, air and ventilation systems turned on, and insect cages retrieved. By startup time Monday, the Eco_2Fume^{TM} phosphine fumigant levels in the atmosphere were non-detectable.

The insect cages were held for 30 days after the fumigation, to simulate the life cycle of confused flour beetle. All of the adult and larval insects exposed to the fumigant were killed. There was no mortality in the adult control cage. The control larvae died; it is thought that improper handling of the cage was the cause. The control eggs hatched into normal larvae over the 30 days following the fumigation. None of the eggs exposed to the fumigation hatched. Thus, 100% of the insects in all stages of life that were exposed to the Eco_2Fume^{TM} combination method were killed.

In addition, pheromone traps for warehouse beetles were placed around the plant before and after the fumigation. No beetles were caught for two weeks following the fumigation.

Finally, FSS calculated the cost of the Eco_2Fume^{TM} treatment and compared it to a comparable methyl bromide treatment. The company calculated a final cost of US$18.53 per 1,000 cu. ft. for MB vs. US$18.06 per 1,000 cu. ft. for Eco_2Fume^{TM}.

Fumigation Services & Supply performed an experimental fumigation at a Pillsbury flour mill and warehouse complex in Hillsdale, MI, in May. At most, 15 tons of CO_2 is introduced into atmosphere.

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ALTERNATIVES TO METHYL BROMIDE FOR THE TREATMENT OF WOOD, TIMBER AND ARTEFACTS IN THE EUROPEAN COMMUNITY

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ABSTRACT

Methyl bromide (MB) is used to control insects and fungi in timber, wood, wood products and artefacts, partially for quarantine and pre-shipment purposes. Research on alternatives to replace MB has identified some physical measures such as heat, irradiation and kiln drying; and some chemical substances such as sulfuryl fluoride, phosphine and hydrogen cyanide. Insects in artefacts of organic origin can be effectively controlled over a relatively long period using humidified nitrogen containing less than 1 vol.-%. oxygen. A non-MB, rapid-acting quarantine treatment has yet to be developed to control fungi such as *Ceratocystis fagacearum* and insects in logs, timber and wood.

Keywords: wood, timber, artefacts, pest control, alternatives, methyl bromide, heat, irradiation, sulfuryl fluoride

INTRODUCTION

Treatment of export logs or at point of import, is one major use of methyl bromide (MB) fumigation (Anon 1998). The procedures are typically carried out against quarantine pests and are required by plant quarantine authorities as a condition of importation. Two major classes of pests require control: insects and fungi. In some instances control of mites, snails and slugs, and/or nematodes, may be needed.

Approximately 5% of the global MB production is consumed controlling insect pests and some fungi of wood products, timber and artefacts in the following applications:

a) Treatment of internationally traded logs also in quarantine: Timber, which is infested by the oak wilt fungus *Ceratocystis fagacearum*, a quarantine pest for Europe, is usually fumigated with MB under gas-proof sheets or in chambers at the high rate of 240 g/m³, prior to export from the USA (Schuerch 1968, Schmidt *et al.* 1982, Rütze & Liese 1983, Kappenberg 1998).

b) Treatment of dwellings and other buildings: Pest control in structures is used to prevent or control pests in either an entire structure, or a portion of a structure. Many conditions exist which require structural pest control; only some of these are treated primarily by MB fumigation (Unger *et al.* 1992). The main application is the control of direct structural damage by wood-boring insects to domestic, commercial and historic buildings. Two major classes of pests require control: insects and fungi.

c) Treatment of wood products also in quarantine: Generally, wood products which require treatment with MB can be classified into two categories: those items separate from buildings and structures, and those forming an integral part of a structure. Wood products include raw material such as logs, sawn timber and products made of wood such as pallets, bamboo ware, packaging materials and other items of quarantine significance. For pests that infest wood products, alternatives for control can be classified into two types of treatments: those that are applied directly to the product, and those that utilise an enclosure for treatment in a confined space. The nematode *Bursaphelenchus xylophilus* is a European quarantine pest that can be found in imported timber, wood and wood products.

d) Disinfestation of museum objects: The preservation and protection of artefacts represents a broad area of interest including commercial aspects and artefacts of substantial value or of irreplaceable cultural and national significance. Many of the objects held in museums, libraries and similar repositories are subject to attack by rodent and insect pests and, under highly humid conditions, by fungi. Infested materials include those made of wood, paper, leather, and skins, feathers, wool and other natural fibres. Artefacts and similar objects made of organic materials are also objects of international trade and may carry pests of quarantine significance. Many museums, libraries and similar repositories have installed a quarantine system to ensure that only insect-free artefacts enter the location. Freezing or treatment with nitrogen gas can be the option for quarantine (Pinniger 1991). Emphasis is thereafter focused on minimising the risk of introducing damaging pests.

Quarantine treatments in international trade require high speed and thoroughness of the disinfestations, which is provided by the use of MB. In museums, longer exposure periods for pest control are not a constraint.

ALTERNATIVES TO METHYL BROMIDE

Chemical Substances

Sulfuryl fluoride

For a), b), c), and d) above: Sulfuryl (sulphuryl) fluoride (SF) was developed in the late 1950s as a structural fumigant, mainly for termite control (Stewart 1957, Gray 1960). It is applied to buildings, which are covered with gas-proof sheets or otherwise sealed. The gas provides good penetration, requires a short fumigation period of approximately 24h against adult insects. The egg stage of many insects appears to be up to 10 times more tolerant than adult insects.

SF is considered a practical alternative to MB for many uses, particularly for quarantine fumigation applications (Woodward & Schmidt 1995) and for use in empty food processing facilities (Reichmuth *et al.* 1997). It is toxic to post-embryonic stages of insects (Kenaga 1957) but the eggs of many species are very tolerant especially at low temperatures, requiring concentrations of over 50 g/m³ and exposures of up to three days for complete kill (Williams and Sprenkel 1990). Eggs of *Ephestia kuehniella* at 25°C required a ct-product of about 1000 gh/m³ to prevent hatch and 800 gh/m³ to prevent emergence (Bell & Savvidou 1999).

SF is currently registered for use under the trade name Vikane®. It is used in some European countries to control a wide range of pests including: wood-destroying beetles, furniture and carpet beetles and clothes moths. Research is ongoing to evaluate the potential of this chemical for timber treatment for plant quarantine purposes (Anon 1998). Efforts are underway to develop treatment schedules to fumigate timber being imported into the USA, Europe and Japan to control wood-destroying beetles or fungal pathogens (Chambers & Millard 1995; Kappenberg 1998).

Phosphine

a) Fumigation of logs using phosphine is effective in controlling bark beetles, wood-wasps, longhorn beetles and platypodids, at a dose of 1.2 g/m³ for 72 h exposure at 15°C or more. The length of time required to complete treatments restricts its commercial acceptability. New developments include phosphine to treat bamboo in transit to avoid MB quarantine treatments in Japan.

b) and d) Phosphine is used to fumigate wooden objects, paper and other materials of vegetable origin. With some materials, e.g. furs and paper, phosphine may be preferred to MB because of the reduced risk of taint. Phosphine may adversely affect metals like copper, silver and gold and pigments in paintings and is therefore rarely used for treating objects of this type. Compared to MB at the same temperature, fumigation with phosphine requires a longer exposure period for complete control of insects.

Hydrogen cyanide

b) The first use of hydrogen cyanide (HCN) for control of *Anobium* spp. dates back to 1921 when the king's castle in Kalmar/Sweden was fumigated (Unger 1988). The formation of chemical complexes with various metals and its high water solubility restrict the application of HCN, but it has potential.

d) HCN is also used for pest control in artefacts, with a recommended dosage of 20 g/m³ for 72 h exposure. The use of HCN is very limited because of its low fungicidal effect and slow desorption, as well as possible reaction with the treated material.

Bifluorides

a) and c) the timber is immersed in a 10% solution of the chemical for five to ten minutes. No monitoring equipment is required. Temperatures must be above freezing. This relatively inexpensive treatment is accepted in many European countries.

Contact insecticides

b) and d) Contact insecticides are used as part of pest management strategies in museums. A variety of specific insecticides based on pyrethroids like permethrin, cypermethrin, deltamethrin, and cy-halothrin or based on organosphates like dichlorvos and chlorpyrifos are the most common. In Japan, artefacts such as museum specimens, collections, books antiques and art crafts are treated with cyphenothrin, applied as a 1% solution in liquid carbon dioxide, to control the cigarette beetle, the powder-post beetle, the black carpet beetle, the book borer, the oriental silverfish and others.

Contact insecticides/preservatives

a) Contact insecticides, including dichlorvos, may be applied as part of a pest management strategy. There is an approved quarantine treatment involving immersion of logs in water and treating the upper surface of the logs above the water level with an insecticide mixture. In the USA and Japan, a dip-diffusion treatment in a solution of borate is registered for sawn timber. Australia allows pressure impregnation of insecticidal mixtures as an alternative to MB for treatment of wooden pallets for control of *Sirex noctilio* and other wood pests.

b) Products such as boric acid, pyrethroids, silica gel, diatomaceous earth and sodium octaborate tetrahydrate, are applied as spot treatments or into cavities created by insects in the wood. Application of dusts can be labour-intensive and requires boring into the wood in the structure.

Physical methods as alternatives to MB

Controlled Atmospheres

a) The efficacy of controlled atmospheres (CAs) with low residual oxygen content at elevated temperatures for treatment of logs for export is being studied in New Zealand (Anon 1998).

b) Carbon dioxide instead of MB has been effectively used for insect control in furniture and artefacts in a large church in Germany. Insufficient sealing resulted in excessive use of carbon dioxide.

c) CAs have the potential for use in wood products but long exposure times are required for treatment at ambient temperatures (Adler *et al.* 2000).

d) CAs are being increasingly used for insect control in artefacts and replace MB in this field. The treatment may take 2 to 8 weeks in gas-tight chambers (Gilberg 1991; Reichmuth *et al.* 1992; Newton 1993; Adler *et al.* 2000). CAs with humidified nitrogen in a carefully constructed gas-tight enclosure, can control all stages of museum insect pests after purging to reduce oxygen contents well below 1 vol.-% and holding the artefacts for up to 30 days in these conditions. Atmospheres with more than 60 vol.-% carbon dioxide in air are proving to be also effective replacements for MB in museums (Newton 1993).

Heat and cold treatments

a) Steam heat or hot water dips are generally most suitable, but kiln drying or dry heat is suitable for sawn timber. Heat treatment by steam has been shown to eradicate all tested fungi when 66°C is held at the centre of wood for 1.25 h (Miric & Willeitner 1990, Newbill & Morrell 1991). Using microwave energy as a heat source is also a possibility.

d) Heat and cold treatments can be used to disinfest artefacts, provided condensation and cracking of wood and other sensitive materials can be avoided by appropriate control of moisture. Exposure to –18°C can disinfest woollen artefacts of clothes moths in a few days (Brokerhof *et al.* 1993). A commercial technique employing heat and humidity to disinfest museum artefacts has been field-tested. Strang (1992) reviewed heat and cold treatments for artefacts.

Irradiation

a) A dose of 6 – 8 kGy kills the nematode *Bursaphelenchus xylophilus*, an economic and quarantine pest of timber (Anon 1998). Collaborative research in Russia and the USA aims to introduce gamma irradiation as quarantine treatment for logs.

c) Some wood products are commercially irradiated on arrival in Australia as a quarantine treatment.

d) Irradiation has been effectively used to control insect and fungal problems in historical artefacts, art objects, and books and paper archives. The minimum recommended dose for pest control ranged between 0.5 kGy to 1.6 kGy for insect control (Fan *et al.* 1988).

MISCELLANEOUS

Under water dipping

a) Dipping logs under water is necessary to improve plywood quality. Immersion of logs in water for more than 30 days suffocates pests and is an approved treatment. The upper surface of the logs above the water level is sprayed with an insecticide mixture. In Japan, approximately 14% of the logs imported in 1992 avoided MB due to the use of this technique.

Removal of bark

a) At present, removing bark from logs prior to export is practised to a very limited extent as a control measure against pests, particularly bark beetles.

c) Debarking, together with conversion to sawn timber in the country of origin, appears to have the potential to reduce a need for MB where bark-borne pests are the objects of the treatment, including quarantine treatments.

CONCLUSIONS

Replacement of MB as a pest control agent is progressing. Sulfuryl fluoride is a good candidate that can be used in many situations. Nitrogen and carbon dioxide with low residual content of oxygen are already considered replacements for MB in museums for pest control of artefacts. Irradiation, kiln drying and other applications of heat seem to be promising new solutions for disinfestation and disinfection of timber and wood.

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PREVENTATIVE CLEANING AND INSPECTION AS AN ALTERNATIVE TO METHYL BROMIDE FOR TREATMENT OF FOOD FACILITIES IN THE EUROPEAN COMMUNITY

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ABSTRACT

Insects and other pests in food facilities constitute an unacceptable health risk and must be eradicated to maintain food safety. Fumigation is reactive, very costly and can cause other problems such as residues, ozone depletion and facility shutdown. A more effective and proactive way of eradicating insects is by sanitation and inspection. A well-integrated cleaning and inspection programme within a food facility prevents insect development and provides a safe environment by reducing the risks of foreign object contamination. This paper describes the cleaning programme, schedules, procedures, record keeping, inspection periods, inspection personnel and training, and expected results. Early detection and eradication of insect activity eliminates the need for pesticide treatment, saves time and reduces costs.

INTRODUCTION

Insects and other pests are a common feature in food facilities. However, in the interest of food safety, they are not acceptable and must be eradicated. Very often, at the first indication of insect activity, fumigation is used on materials and on facilities. However, fumigation is a reactive method, it is very costly and can engender other issues including fumigant residues, ozone depletion and facility shutdown. A more effective and proactive way of eradicating insect activity is through sanitation and inspection. Indeed, the best prevention method against insects and pests in a food facility is thorough cleaning and inspection. If insects are denied food and a time interval in which to breed, they will go elsewhere. A comprehensive, integrated cleaning and inspection programme within a food facility will not only prevent the development of insect activity but also provide a safe environment, improve food safety by reducing the risks of foreign object contamination and provide support for a sound "due-diligence" programme.

CLEANING PROGRAMME

Cleaning is an essential and integral part of any successful food or food related business. Cleaning will prevent risks of contamination from micro-organisms, foreign objects and insects.

A robust cleaning programme must start with the commitment and involvement from people at all levels in the development of the programme. Cleaning standards must be set, clearly defined and communicated and everyone must be personally committed to ensuring that satisfactory standards are constantly achieved. All personnel should be instructed and motivated through training and communication. The system should be easy to use and practical. In addition adequate resource of staff, materials and equipment should be available. The more time spent on cleaning, the less time and expense will be required to use chemicals to eradicate insect problems.

A planned approach to cleaning is essential to prevent infestation and contamination. Cleaning can be divided into three categories: housekeeping, periodic cleaning and deep cleaning.

Housekeeping covers clean-as-you-go tasks such as floor sweeping, spillage removal and regular surface cleaning. Removal of spillage and debris inside as well as outside the facility will make the area unattractive to rodents, birds, insects and other pests. Housekeeping should cover areas such as grain receiving pits, grain spillages, removal of sweeping bags and waste dump areas.

Periodic cleaning refers to equipment and areas that need to be cleaned on a frequent basis, according to a pre-planned schedule and following documented cleaning procedures. Periodic cleaning must be recorded and the use of a Master Sanitation Schedule (MSS) is useful in the planning, monitoring and communication process. Examples of items to include on an MSS would be grain receiving pit, drag conveyors, the base of elevators, housings, dead-ends such as the drives to conveyors, under silos, tunnels and harvesting equipment.

Deep cleaning refers to equipment or areas which cannot be cleaned periodically because of their location, convenience, the need for special cleaning equipment, and may require the hire of an external company. For instance, interiors of silos can only be cleaned when the silos are empty and special equipment for silo entry such as harnesses can be required. Walls, ceilings, overhead beams, roofs, silos and stores will need to be deep-cleaned at least once a year, depending on the location, weather, temperature and likelihood of insect ingress.

CLEANING SCHEDULES / MASTER SANITATION SCHEDULE

A cleaning schedule is a list of all areas and items that require cleaning. It must also include the frequency of cleaning and the person(s) responsible for carrying out the cleaning. When this is compiled, it should provide a visual overview of the cleaning requirements in the whole facility and is referred to as a Master Sanitation Schedule. An MSS is a plan of the work to be completed during the year ahead. It is usual for each area/department to have its own MSS. Figure 1 shows an example of MSS. This schedule allows you to see at a glance what needs to be done on a weekly basis.

Figure 1: Example of a Master Sanitation Schedule in a grain receiving area

Task	Frequency	Respons-ibility	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8
Receiving Pit	Weekly	X	■	■	■	■	■	■	■	■
Elevator	Two weekly	Y	■							
Conveyor A	Two weekly	Y								
Conveyor B	Two weekly	X								
Tunnel	Three weeks	X								
Ceiling	Monthly	Y								
O/h beams	Monthly	X								
Silo	Two months	Y								

Frequency of cleaning will depend on the type of area, external factors such as temperature and on the life-cycle of the targeted insects. Equipment and areas prone to insect infestation should be cleaned on a minimum of a weekly basis and no less than once a month.

The MSS should include tasks to be completed on and appropriate basis such as weekly, monthly or quarterly, and should be accompanied by a cleaning procedure. The schedule can be modified according to the level of dust accumulation. Harvest equipment and other equipment only used seasonally can be put on a modified schedule.

CLEANING PROCEDURES

Equally important to the MSS are the cleaning procedures that will explain what needs to be cleaned, how, when, why, by whom, with what and so on. For all weekly and periodic cleaning tasks, a fully detailed procedure is required. The procedure should indicate:

- Task, location, frequency, cleaning responsibility and inspection responsibility;
- Supplies and materials, i.e. equipment and chemicals required to carry out the task such as vacuum cleaner, hoses, tools, eye protection, gloves, brushes, cleaning chemical preparation;
- Safety measures and critical points which must be undertaken to safeguard the people and the products, e.g. the system must be emptied at the end of the production run, electrics must be covered, area must be isolated. For many specialist areas such as silos, a full Health and Safety risk assessment should be undertaken to minimise the possiblity of accidents;
- Step by step method of cleaning, e.g. remove all lids from the conveyor. Keep bolts and nuts in a safe place. Vacuum out all dust and debris in the conveyor, in the dead ends, in the motion sensor, in the slide gates. Replace the lids and all nuts and bolts; and

- Standard of cleaning to be achieved, e.g. all dust, old product and debris must be removed; clean from top to bottom; inspect and clean ledges inside equipment/silos.

If external contractors are to be used, they should be given, or they should develop cleaning procedures and schedules, in line with company standards.

CLEANING RECORDS

The provision of cleaning records is an essential part of a “due-diligence” defence. Any cleaning undertaken should be recorded on the MSS. This enables you to check progress-to-date and what tasks remain outstanding. Tasks should be signed off on completion by the person who carried out the cleaning and also by a responsible person, such as the Hygiene or Area Manager, upon inspection of the cleaning standards.

INSPECTION PROGRAMME

Although a good cleaning programme will certainly reduce insect activity, it will be even more effective if it is integrated with a good inspection programme. Inspections will not only allow for early detection of insect presence, but also identify poor cleaning practices and potential risks of contamination. To that end, an internal inspection programme should be in place at the food facility.

INSPECTION FREQUENCY

Inspection frequency should be tailored to the type of insects and their life-cycle, to the location of the facility (warm/cold country), to the time of the year (winter/summer), but the recommended frequency is a minimum of once a month.

PHYSICAL INSPECTION

The internal audit must consist of a physical inspection and an audit of procedures and records. The physical inspection must be very thorough and detailed. Adequate equipment must be used, such as a torch to look into dark corners and places, a scraper to look for insect activity, a flexible mirror to look under or behind equipment, a screw-driver to open electrical panels, drives or lids, and of all these whilst compliant with the Health and Safety legislation.

Insect activity will start outside the facility, therefore all areas of the facility, including roof and external grounds must be inspected in order to evaluate and prevent attraction of insects. Such attraction could be pools of water, product debris, old equipment and other items.

Physical inspection does not mean strolling around the facility, but inspecting every corner, every room, every ledge, every gap, underneath, over, on the sides, inside equipment. It would be wise to wear appropriate clothing.

INSPECTION SCHEDULE

The food facility should be divided into sections, and only one section should be inspected at a time, on a rota basis. The inspections need to be very thorough, and inspecting the whole facility at once could lead to tiredness and lack of attention and issues could be missed. For instance, the facility could be divided into four sections, and a different section could be inspected every week.

INSPECTION TEAM

The inspectors should receive adequate audit training. The inspection should be carried out by a cross-functional multi-disciplinary team. For example, inspections will be much more effective if a new pair of eyes are brought in every now and then. Although the inspection programme should be the responsibility of the Food Safety Manager, personnel from different functions within operations, such as raw materials, finished goods or manufacturing; and front line operators as well as managers should take part in the audit process.

RECORD KEEPING

At the end of an inspection, the auditor should give verbal feedback on the audit outcomes to the plant management team. Key points and comments should be raised and any corrective actions required should be time-bound, discussed and agreed. A written audit report, including issues, corrective actions and time limits, should be left on site.

Where a non-conformance or insect activity has been identified, there is a need not only to correct the immediate situation but also to identify, where possible, the underlying cause of the problem. Once this has been identified, actions should be taken to prevent recurrence.

OUTPUT

A comprehensive and preventative cleaning and inspection programme will render the facility unattractive to insects and therefore remove the need for chemical treatment.

Such a programme must not only be in place in the food facility, but must be applied to the whole crop to consumer chain, this chain only being as strong as its weakest link. Cleaning and inspection of equipment should take place at every stage of the production process, from site selection, to site preparation, to plantation, to crop management, to harvest, to transport. Early detection and eradication of insect activity, through inspections and effective cleaning, eliminates the need for pesticide treatment, hence saving the facility time and money.

ALTERNATIVES TO METHYL BROMIDE FOR TIMBER TREATMENTS

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ABSTRACT

This paper describes some of the consequences of the Biocidal Products Directive 98/8/EC on the authorisation of wood preservatives and approval of active substances in the European Community. Consideration of the environment, human safety and treatment cost is required when searching for alternatives to methyl bromide for wood treatments. Further research is required to find biological agents or natural products that have low environmental impact, physical treatments and to determine risk evaluation based on the location of where the wood presevation is carried out.

Keywords: Biocides products directive, methyl bromide, risk assessment, wood preservation, wood preservatives.

INTRODUCTION

The Biocidal Products Directive 98/8/EC covers the placing of biocidal products on the European Community market and establishes which active substances, including substances or microorganisms that work with general or specific action against hazardous organisms, are approved for use within the European Community. The biocidal products containing these active substances must be approved for use in any Member State in which it could be registered for commercial use. The authorisation obtained in a Member State in which the product is first registered should be recognized by the other Member States.

The aim of the BDP is to ensure a harmonised, high level of protection for human, animal and the environment for the use of biocidal products. BDP also creates a European market without internal constraints. This Directive, from the legislation point of view, its very complex as it requires core data common to all active substances and biocidal products. In addition, specific data requirements are defined for each of the 23 biocidal products by type. The BPD covers all products as well as their variations in risk.

Technical Guidance Notes (TGNs) provide full details on the toxicologocial, ecotoxicological and efficacy tests required for the different biocidal products and their active's substances. TGNs are now finalised (December 1999) and are to be used as reference for all chemical active substances but not for the biological biocides.

Type 8 products within the BPD list are defined as "products used for the preservation of wood, from and including the raw-mill stage, or wood product by the control of wood destroying or wood-disfiguring organisms". These products may have preventive and curative character. Methyl bromide (MB) may have a curative character that destroys organisms that infect wood it cannot protect against reinfection.

Active substances used in wood preservation that were on the market before 14 May 2000 must be revised before 27March 2004 according to Commission Regulation 1896/00. Products containing one or more active substance that were on the market before 14 May 2000 must be authorised following the specific details and technical process for product assessment contained in the BDP Directive and its TGNs.

Due to this Directive, some current wood preservative formulations may be, in a short period of time, out of the market because the costs of generating the data and the preparation of the dossier makes the product uneconomic. It is extremely unlikely that any new active substance will be developed only for use as a wood preservative as it would not be economic. The wood preservation industry is concerned there will be discontinuity of future preservative supplies due to a lack of warranty for active substances.

Other problems outlined by the BPD relate to the difficulty of meeting the informational requirements for their final authorisation of wood preservatives due to the lack of information allowing a correct risk assessment. Several situations should be considered:

- Applications method (brushing, dipping and vacuum-pressure impregnation);
- Domestic or industrial applications;
- Personnel qualified or not; and
- Wood treated by different type of exposure: indoor, outdoor, ground contact or without, continued or discontinued submersion in water.

To compensate for this lack of information in the past years, many initiatives had been formulated. The most important actions have been:

- COST E2 Wood Durability;
- European Wood Manufacturers Group;
- OECD workshop on "Assessing Environmental Exposures to Wood Preservatives";
- Working Groups of TEC 38/CEN (WG 21, Natural Durability and Risk Types and WG 27 Exposure Aspects); and
- COST E22 Wood ´s Environmental Optimisation.

Many of these working groups and meetings achieved improvements for the final version of the TGNs, but still many points are not resolved. For example, environmental risk assessment depends on the place and conditions where the wood treatment is taking place (industrial or domestic application). Also there is no consideration of the risks produced during the wood treatment itself or during the final drying process, as well as the problems caused by elimination of treated woods.

The situation of wood preservation is complicated by the fact that treated wood is the main product for construction and must fulfil the essential requirements of the Construction Products Directive (89/106/ EEC), especially the characteristic of durability.

In order to reduce the toxicological and ecotoxicological risks required by BPD without reducing the efficiency of wood treatments it is necessary to carry out fundamental research in wood protection in the following areas:

- Protection with biological agents or natural products. This could be of interest due to the low impact on the environmental but they are generally are not economically competitive;
- New chemical wood preservatives with high level of efficiency with less toxicological risks and known to be harmless to the environment;
- Physical treatments; and
- Environment risk evaluation according to where the wood is preserved.

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USE OF NON-CHEMICAL METHYL BROMIDE ALTERNATIVES IN THE USA

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INTRODUCTION

About 30% of the methyl bromide (MB) used in the United States is for post harvest and structural treatments. Much of the post harvest use is to meet phytosanitary standards for international trade. The United States Department of Agriculture, Animal & Plant Health Inspection Service, Plant Protection and Quarantine (USDA, APHIS, PPQ) supports the continued use of MB for quarantine and pre-shipment treatments as exempted under the Montreal Protocol. The agency believes it is important, however, to develop and adapt alternative technologies that can lead to reduced gas emissions and overall use. This position has been adopted, in part, due to uncertainty as to how the U.S. Environmental Protection Agency will define both quarantine and pre-shipment applications (US EPA 2001). Thus, PPQ and the Agricultural Research Service (ARS) have active research programs for developing MB alternatives, both chemical and non-chemical. While some of the technologies are in their infancy, others have matured and are currently in use or will be approved for use this year.

The national phytosanitary organization for the United States is PPQ which approves all treatments that meet quarantine standards for commodities being imported into the country and for certain commodities, such as propagative plant material, and agricultural equipment moving within the country. The PPQ Treatment Manual currently lists heat, cold and irradiation as acceptable non-chemical treatments that meet quarantine standards (USDA 2002). Some of these treatments are alternatives to methyl bromide fumigation while others are used on commodities that are sensitive to the treatment. Non-chemical MB alternatives also are in use for non-quarantine applications such as those used for structural treatments. During the search for effective alternatives to MB, PPQ will systematically review all approved treatments to ensure they continue to work properly.

NON-CHEMICAL ALTERNATIVES

High Temperature

High temperature treatments are being evaluated and adopted as non-chemical alternatives for both quarantine and structural treatments. Several high temperature quarantine treatments were developed in the 1980s as an alternative to ethylene dibromide fumigation, which was considered to be carcinogenic. MB was not adopted at that time due in part to phytotoxic effects of the gas. Other heat treatments were developed specifically to be alternatives to MB.

Some winter wheat fields in Texas were infected with Karnal bunt, *Tilletia indica*, in 2001. When infected grain was harvested and transferred to storage bins, the bins and grain handling equipment became infected. Once emptied, MB fumigation of contaminated storage bins requires a dose of 6.8 kg for 96 hours to meet quarantine standards. Steam heating to a point of runoff in bins also is effective when surface temperatures attain 77°C.

The golden nematode (*Heterodera rostochiensis*) is a potato pest of quarantine significance that occurs in a few isolated areas of the northeastern United States and in other countries. Used farm equipment, construction equipment, and containers infected with the nematode require a MB treatment of 6.8 kg for 24 hours to meet quarantine standards. Heat treatment using steam is effective for treating golden nematode infected equipment. Brodie and Norris (2001) injected live steam into a tent containing a tractor that was contaminated with all life stages of the nematode. A one-hour treatment at temperatures above 60°C resulted in 100% mortality of all life stages. The specific treatment parameters are being developed and the alternative will be approved for use. A preliminary test using the same technology to kill an introduced Mediterranean snail, *Cernuella cisalpina*, infesting maritime shipping containers (MilVan) resulted in 100% control when temperatures exceeded 54° C for 20 minutes (Mack and Norris unpublished data). The current treatment schedule for quarantine significant snails is 3.6 kg MB for 24 to 72 hours.

Dry heat is an effective non-chemical alternative and can be used in situations where the use of steam is not practical or there are concerns about water damage that may occur from steam treatment. Heat treatment is not a new technology and its use to disinfest flourmills predates MB fumigation (Goodwin 1922). Heat treatments were abandoned when fumigants became economically practical and due to fire safety concerns and perceived damage to wooden equipment. With the impending phase out of MB, however, the milling industry revisited this technology and its use is increasing. Recent advances have increased the effectiveness of the treatments and documented that modern food processing facilities, as well as older wooden structures and equipment, can be safely heat treated to temperatures of 50 to 60°C (Dowdy 1999, 2000; Dowdy and Fields 2002; Fields *et al.* 1997; Mueller 2002).

Low Temperature

Temperatures at or slightly above 0°C are effective for controlling a variety of insects, especially fruit flies, with minimal impact on commodity quality. A drawback of low temperature treatment is the length of time necessary for adequate control. While high temperatures in a matter of minutes can kill most insects, low temperature treatments may require several weeks or months to achieve the same level of control (Fields 1992). Further, low temperatures have little if any effect on the viability of most plant pathogens. Low temperature treatments conducted in-transit are not as limited by the time requirements needed for control and have been effective for many years. Recent failures of low temperature in-transit treatments, however, have resulted in a re-evaluation of the treatment with an emphasis on adequate distribution of the treatment temperature throughout the container or ship hold.

Irradiation

The use of irradiation as a commodity treatment has been discussed for several years but has yet to develop into a widely adopted method for safeguarding agriculture and natural resources. Its use as a quarantine treatment was conceptualized in 1930 (Koidsumi 1930) but was not commercially demonstrated until 1986 when shipments of mangoes from Puerto Rico were irradiated with 750 Grays and sold in Florida (Hallman 1998). Although irradiation was effective, a hot water immersion treatment was developed as the official mango treatment. In 1995, tropical fruits were shipped from Hawaii to Chicago for irradiation and distribution to markets. Since then, an irradiator has been built near Hilo, Hawaii that treats tropical fruits for unrestricted distribution on the mainland. Market surveys and approval in 2000 by the U.S. Food & Drug Administration for the irradiation of meat products indicate consumer acceptance of irradiated foods.

The objective of using irradiation, as with any quarantine treatment is to prevent the establishment of exotic pests. To accomplish this task, pest mortality is not always necessary, particularly with insects. Rather the prevention of reproduction should be the goal, which can be accomplished at lower doses than 100% mortality.

Presently, PPQ has approved irradiation quarantine treatments for three tropical fruits from Hawaii only. These are papaya, carambola and lychee for the pests Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann)), melon fly (*Bactrocera cucurbitae* Coquillett) and Oriental fruit fly (*B. dorsalis* Hendel) (Treatment Schedule T105-a). The schedule requires a minimum dose of 250 Grays and a maximum of 1,000 Grays with documented dose mapping for each commodity, fruit size and box configuration. Additionally, irradiated commodities are to be safeguarded after treatment to ensure that they do not become reinfested.

The USDA APHIS published a proposed rule to establish phytosanitary requirements that will allow the use of irradiation treatments for imported fruits and vegetables (USDA 2000). The key elements of the rule address critical control points including irradiation doses and safeguarding after treatment. The proposed rule establishes irradiation doses for 11 fruit flies and one seed weevil (Table 1). The treatment is based on the pest requirements rather than on the commodity. This means that any commodity can be irradiated at the proper minimum dose for any of these species. For commodities where more than one pest is present, the highest dose is required. If other pests of quarantine significance are also of concern on a particular commodity but are not listed in the rule, then irradiation is not considered to be an adequate quarantine treatment for that pest. For example, if the quarantine pests of concern for a particular host are the melon fly that is listed in the rule, and a noctuid moth that is not listed, then a different approved treatment must be used to mitigate the risk caused by the moth. A supplemental proposed rule is currently being developed that concerns the use of radiation indicators on packaging of treated articles and additional provisions for monitoring of foreign facilities that provide the treatments.

TABLE 1: Irradiation dose for fruit flies and seed weevil in imported fruits and vegetables[1]

Common name (scientific name)	Dose (gray)
Oriental fruit fly (*Bactrocera dorsalis*)	250
Mediterranean fruit fly *(Ceratitis capitata)*	225
Melon fly *(B. cucurbitae)*	210
South American fruit fly *(Anastrepha fraterculus);* Caribbean fruit fly *(Anastrepha suspensa);* Mexican fruit fly *(A. ludens);* West Indian fruit fly (*A. oblique)*; Sapote fruit fly *(A. serpentina);* Queensland fruit fly *(B. tryoni); B. jarvisi*; Malaysian fruit fly *(B. latifrons*)	150
Cryprorhynchus mangiferae Mango seed weevil	100

[1] Adapted from USDA 2000

CONCLUSIONS

The non-chemical alternatives in use today are not new technologies but need to be revisited and re-engineered as potential alternatives to MB. Although new fumigant chemistry offers some alternatives, there will be no "drop-in" replacement for all uses of MB. Non-chemical alternatives can be as effective but adequate monitoring and verification are needed to ensure that treatments are efficacious and properly applied. The use of heat, cold and irradiation require closer attention for proper treatment than MB because pests may not be dead after application and a treatment failure may not be recognized until a commodity is widely distributed. Further, greater effort will be needed in crop production, such as the effective use of integrated pest management and systems approaches, to minimize the number of pests present in a commodity at harvest. Such practices will reduce the number of pests challenged by a treatment while maintaining or enhancing commodity quality.

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LOW TEMPERATURE STORAGE OF FOOD AND OTHER ALTERNATIVES TO METHYL BROMIDE

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ABSTRACT

Cold treatments are predominantly used to inhibit decay of stored commodities and to extend their shelf life. Recently, cold treatments have been used successfully to control insect pests, mainly in tropical commodities, providing chilling injury can be avoided. This paper summarises the main uses of cold storage as a quarantine treatment.

Keywords: low temperature food storage, quarantine, chilling injury.

INTRODUCTION

Insects are poikilothermic animals. Their development is only possible between lower and upper temperature thresholds. Beyond these values, and depending on the time of exposure, temperature becomes lethal. Cold storage of food takes advantage of this physiological response of insects and can be a useful alternative to the use of methyl bromide (MB) as a postharvest treatment.

Low temperature storage is primarily used to inhibit decay and extend the shelf life of food commodities. Modern fresh fruit industry greatly depends on technology providing refrigerated facilities and transportation. When a combination of temperature and time of exposure exists that assures quarantine requirements (probit 9: 99.9968% mortality) (Baker 1939), and does not lead to unacceptable fruit damage, cold has a potential as a quarantine treatment, especially for those commodities where low temperature storage is used as part of the regular distribution and marketing practice.

Research on the use of low temperatures to control insect pests began at the end of the nineteenth century and expanded to cover a variety of food pests early in the twentieth century. Pests of stored products, such as the webbing clothes moth, *Tineola bisselliella* (Hummel) (Lepidoptera: Tineidae), the dark mealworm beetle, *Tenebrio obscurus* F. (Coleoptera: Tenebrionidae), or the cabinet beetle, *Trogoderma tarsalis* (Melsh) (Coleoptera: Dermestidae) were among the first to be tested (Gould 1994). Nevertheless, the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) soon atracted most of the attention. This pest was becoming established in new areas and was a serious concern for many import countries.

Cold storage was used as a quarantine treatment for the first time against *C. capitata* in Florida in 1929 (Richardson 1958). Since then, low temperature storage has been developed and successfully applied as a quarantine treatment against fruit flies (Diptera: Tephritidae) occurring mainly in temperate fruits (Table 1). A standard cold treatment against *C. capitata* requires a temperature of 2.22ºC (or below) for 16 days, and this is usually applied in transit (Anon 1992).

There are strict requirements for temperature monitoring in cold storage facilities in order to certify compliance with the required cold treatments. Cold quarantine has also been successfully applied to other insect taxa (Table 1), but problems have arisen from either the occurrence of extraordinarily cold-resistant stages (Moffit & Albano 1972), or cold habituation (Meats 1976; Czajka & Lee 1990).

Studies involving tropical fruit, such as mangoes, guavas and longans have usually resulted in unacceptable cold damage and have not been commercially used (Burditt & Balock 1985; McGuire 1998a). To prevent this kind of damage, preconditioning of fruit can be important (Hatton & Cubbenge 1982; Wild & Hood 1989; Houck *et al.* 1990; Miller *et al.* 1990; Crisosto & Smilanick 2000). Chilling injury may also be prevented by use of plant growth regulators (Ismail & Grierson 1977; McDonald *et al.* 1988), other chemical treatments resulting in curing the fruit (Schiffmann-Nadel *et al.* 1972; Wardowski *et al.* 1975; Chalutz *et al.* 1985; McDonald *et al.* 1991), and plastic wrapping (Ben-Yehoshua 1985; Yokohama *et al.* 1999b). Harvesting fruit in a less susceptible stage of ripeness can also reduce chilling damage (Chan 1988; Crisosto & Smilanick 2000) and pest incidence in the field. Besides this, cold storage can be part of a multiple quarantine treatment including the combined use of temperature and controlled atmospheres, fumigation, or irradiation (Anon 1994; Anon 2001).

Low temperature storage has been used for a long time as a quarantine treatment, mainly for those commodities where cold storage was already part of their marketing procedure. Use of this technology should increase as research provides new ways of preventing chilling injury.

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TABLE 1: Pests and food commodities for which cold quarantine treatments are feasible.

Target pest	Commodity	Country of origin	Observations	References
Mediterranean fruit fly, *Ceratitis capitata* (Dip.: Tephritidae). Fruit flies in general.	Apple, apricot, cherry, etrog, grape, grapefruit, kiwi, loquat, lychee, nectarine, orange, passion fruit, peach, pear, persimmon, plum, pomegranate, quince, tangerine	Many (>68)		Several: Annon. 1992; Clayton 1993
Caribbean fruit fly, *Anastrepha suspensa* (Dip: Tephritidae)	Lychee Carambolas Citrus	Florida, USA Florida, USA USA	 +cold water treatment + harvesting practices	McGuire 1998b Gould & Hennessey 1997; Gould & Sharp 1991; Miller et al 1998 Benschoter, 1987
Omnivorous leafroller, *Platynota stultana* (Lep: Tortricidae); Black widow, *Lactrodectus mactans* (Araneae: Theridiidae)	Table grapes	California, USA	+SO_2	Yokohama et al. 1999a
Glassy winged sharpshooter, *Homalodisca coagulata* (Hom: Cicadellidae)	Table grape	California, USA		Scott & De Barro 2000
Hessian fly, *Mayetiola*	Hay	USA	+ harvesting,	Yokohama et al. 1999b

Target pest	Commodity	Country of origin	Observations	References
destructor (Dip: Cecidomyiidae)			handling and shipping practices	
Asian citrus psyllid, *Diaphorina citri* (Hom: Psyllidae)	Curry leaves	Florida, USA		McGuire 1999
Apple maggot, *Rhagoletis pomonella* (Dip: Tephritidae)	Apples	Canada	+ controlled atmosphere	Annon. 1994
Plum curculio, *Conotrachelus nenuphar* (Col: Curculionidae);blueberry maggot, *Rhagoletis mendax*; apple maggot, *R. pomonella*;	Apple, apricot, blueberry, cherry, hawthorne, huckleberry, nectarine, peach, pear, plum, prune, quince	USA		Stout and Roth 1983 in Gould 1994
Indianmeal moth, *Plodia interpunctella* (Lep: Pyralidae)	Dried fruits an nuts	USA		Johnson et al 1996
Codling moth, *Cydia pomonella* (Lep: Tortricidae)	Pome fruits, stone fruits and walnuts	USA	+ controlled atmosphere	Annon. 2001

ALTERNATIVES TO METHYL BROMIDE FOR USE AS QUARANTINE AND PRE-SHIPMENT TREATMENTS IN DEVELOPING COUNTRIES

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ABSTRACT

While the use of methyl bromide (MB), an ozone depleting substance, is being phased out, its use for Quarantine and Pre-Shipment (QPS) treatments are exempted from the freeze, reductions and phase out schedules. About 21% of the estimated global consumption for QPS are consumed in developing countries. Alternatives to MB currently used as well as those under development include phosphine, sulphuryl fluoride for timber, carbon dioxide for stored grain, heat treatment, hermetically sealed storage, controlled atmospheres, irradiation and combined treatments such as protein coating with steam for spice and vacuum steam flow processes for leaf tobacco. Contractual obligations should be reviewed in the light of the development alternatives to promote non-MB uses in developing countries as soon as they become available.

Keywords: methyl bromide alternatives, quarantine and pre-shipment treatments, developing countries.

INTRODUCTION

Methyl bromide (M)B was listed as an ozone depleting substance in 1992 and a phase out schedule was agreed in succeeding meetings of the Parties to the Montreal Protocol. In the same year, developing countries (see the list of more than 120 developing countries on UNEP website on www.unep.org) accounted for about 20% of global consumption. In 1996 MB consumption increased to 25% and gross consumption in each region was: Latin America and the Caribbean 6,616 tonnes (38%), North and South Africa 4,269 tonnes (25%), Asia and the Pacific 4,177 tonnes (24%), Middle East 2,120 tonnes (12%) and CEIT[5] developing countries 141 tonnes (1%). MBTOC is currently undertaking a review of consumption in developing countries and will report the results in the MBTOC 2002 report to be released at the end of the 2002.

MB is used under diverse geographical conditions found in developing countries; for soil treatments (70%), for fumigation of durable and perishable commodities (27%), and structures (3%).

Quarantine and Pre-shipment[6] (QPS) treatments, accounting for 23 –26% of global consumption, are exempted from the freeze, reductions and phase out schedules. Of the estimated 15,350 to 17,500 tonnes recorded from various sources in 1996, 21% are estimate use in QPS in developing countries. There may be inconsistencies on reported QPS data as some countries combined quarantine data with pre-shipment data while others reported them separately (MBTOC 1998).

MBTOC (1998) noted that MB was used mostly on cash crop exports such as tobacco, cut-flower, strawberry, banana and vegetable crops. MB was also used for QPS as a condition of entry by importing country, usually at the request of developed countries.

METHYL BROMIDE FUMIGATION OF DURABLE COMMODITIES AND STRUCTURES

MB is frequently used in the treatment of commodities such as grains, beans, dried spices, wood, timber and wood products, bamboo crafts and tapioca, prior to import and export because of QPS requirements. Specifically, in some parts of Southern and Eastern Africa, the commodities treated were reported as dried spices, timber and wood products, coffee and grain and in some Latin America

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[5] Countries with Economies in Transition

*[6] See definitions of QPS in paper by Batchelor, page ** of these Proceedings. MBTOC has also provided a logic diagram to assist in determining whether a MB treatment should be categorised as quarantine or pre-shipment (MBTOC 1998 Assessment, Annex 8.1, p. 303).*

countries the list included coffee, rice, cotton maize, wheat, beans peanuts, soybean, sorghum and timber. On an annual basis, the total quantity of MB used in developing countries for durable commodities is about 20%.

MBTOC noted that purchasers frequently required in the contract the use of MB at very high rates to insure pest free quality that exporting countries have to follow. To a lesser extent purchase contracts require the use of phosphine for pre-shipment fumigation. When the fumigant was not specified in the contract, often MB was selected in preference because of the short time for the treatment. Some countries, however, also specified that MB was not to be used.

Small quantities of MB (less than 3% of developing country consumption) were used for the treatment of empty structures, including warehouses, flour mills, ships, aircraft and other transport vehicles.

ALTERNATIVE FOR MB ON DURABLES AND STRUCTURES

There are many alternatives to MB (Table 1) and phosphine is one of the more effective alternative fumigants for durables and structures that has been proven commercially. It can directly substitute for MB in treatments of many durable commodities when properly used and applied. It is used in the protection of stored products in developing countries. Good management strategies and practices are observed in using phosphine to prevent further pest species becoming resistant to phosphine and thereby prolong its usefulness as a fumigant.

Rice stocks were reported to be routinely fumigated with carbon dioxide on a large scale for many years in Indonesia where there are stocks to be carried over from one season to the next.

Other alternative technologies used for treatment of durable commodities include sulphuryl fluoride (timber in China), carbon dioxide (stored grains in bag stacks in Zimbabwe, Indonesia, Philippines and Brazil and vertical silos in Kenya), heat treatments, hermetically sealed storage, controlled atmospheres, irradiation and combined treatments such as protein coating with steam for spice and vacuum steam flow processes for leaf tobacco.

Table 1: Use of Alternatives for durable commodities in developing countries

Commodity	Alternative	Countries	Comments
Black pepper	Phosphine	Malaysia	Registered for use; widely used-storage
Coconut products	Phosphine	Philippines	Registered for use; mostly for export
Coffee	Phosphine	Vietnam	Registered for use; widely for export
Grain (rice)	Ca rbon dioxide	Indonesia	Long term storage for carryover stocks
Grain (rice)	CO_2 + Phosphine	Philippines	Long term storage for security reserves
Grain (rice)	Carbon dioxide	Vietnam	Use increasing
Grain (barley)	Pre-mixed CO_2 & Phosphine	Cyprus	Currently in use
Grain	Controlled atmosph.	China	Adopted and use expected to increase
Grain	Diatomaceous earth	China	Experimental – used to avoid fumigation
Grain	Phosphine	Dev Country	Use continues to increase
Grain (rice and barley)	Hermetic sealing/ Storage	Philippines & Cyprus	Technology available for adoption
Peanuts	Nitrogen	India	Commercial –retail packages
Rice	Irradiation	Indonesia Thailand	Indonesia –limited commercial use Thailand – experimental use
Rice	Carbon dioxide	Thailand	Commercial – retail package
Timber	Heat	China	Limited use
Timber	Sulfuryl fluoride	China	Use increasing, but trials needed
Tobacco	Phosphine	Many dev. countries	Widely used
Wheat	Carbon dioxide	Kenya	Experimental in silos

Source: MBTOC 1998 Assessment

Potential chemical alternatives for pest control in structures include fumigants such as sulphuryl fluoride (not registered for structures containing foodstuffs), surface spray pesticide such as chlorpyrifos-methyl, pirimiphos-methyl, fenitrothion, malathion and other contact insecticides (Table 2).

Table 2. Use of alternatives for structural pests in developing countries

Commodity	Alternative	Countries	Comments
Grain mills	Cold CO_2+phosphine	Argentina	Experimental
Grain mills	Hot CO_2+phosphine	Chile	Commercially used
Empty containers & buildings	Sulphuryl fluoride	China	Widely used

Source: MBTOC 1998 Assessment

Alternatives that are in use in many developing countries vary according to pesticide registration requirements, commodity, capital investment and the need for additional research.

MB FUMIGATION OF PERISHABLE COMMODITIES

The majority of MB usage in perishable commodities is dictated by the quarantine and other phytosanitary requirements of importing countries. Perishable commodities include cut flowers, stem cuttings, bud-wood, rooted plants, bulbs, corms, rhizomes, fresh fruits, including grapes bananas and vegetables. About 8% of MB in developing countries is used in traded perishable commodities.

ALTERNATIVES FOR MB TREATMENT ON PERISHABLE COMMODITIES

Alternative quarantine treatments, such as a cold treatment, are already used for apples exported from Chile, Jordan, Mexico and Uruguay to the USA; for plums and apricots from Morocco to the USA; and for kiwifruit from Chile to Japan. Heat treatments are also used to disinfest papaya, mango, citrus, eggplant, zucchini, squash, and bell pepper and could be developed for other perishables. Combination treatments, such as soapy water with wax, are used for cherimoya exported from Chile and vapor heat with cold treatment for lychee exported from Taiwan (Table 3).

Table 3: Use of alternatives for perishable commodities in developing countries

COMMODITY	ALTERNATIVE	COUNTRY	COMMENTS
Apples	Wax coating	Chile	Widely used
Apples	Pre-shipment inspection & Certification	Chile	Approved for exports to USA
Apples	Cold treatment	Mexico, Chile, South Africa	Approved for exports to USA
Cherries	Cold treatment	Chile	Approved for exports to USA
Cherimoya	Soapy water + Wax coating	Chile	Approved for exports to USA
Citrus	Wax coating	Chile	Widely used
Citrus	Cold treatment	South Africa	Approved for exports to Japan
Citrus	Cold treatment	Many countries	Approved for exports to USA
Cut flowers (orchids)	Chemical dips	Thailand	Experimental
Cut flowers	Pressure water spray + insecticide	Several countries	Approved for exports to USA
Garlic	Phosphine	China	Widely used
Guava	Hot water dipping	Vietnam	Experimental
Lychees	Vapor heat + cold	Taiwan	Approved for exports to Japan
Mangoes	Heat treatment	Taiwan	Approved for exports to Japan
Melons	Certified pest-free zones	China(one region)	Approved for exports to Japan
Orange	Irradiation	China	Experimental – for imported fruit
Stone fruit – peaches plums apricots	Cold treatments	Morocco	Approved for exports to USA
Stone fruit	Double inspection	Chille	Widely used

Source: MBTOC 1998 Assessment

Other quarantine treatment/procedures approved by certain countries include pre-shipment inspection, pest-free zones or periods, the system approach, controlled atmospheres and physical removal of pests or soil. Each treatment is dependent upon the commodity, the target pest and the geographical area of origin and the requirements of importing countries.

PROBLEMS ENCOUNTERED IN ADOPTING ALTERNATIVES

Phosphine has been used as one of the main alternatives to MB for QPS uses in developing countries. MBTOC identified constraints in the use of phosphine for structural fumigation including:

Longer fumigation period than MB in achieving full effectiveness which may delay importation/exportation period. The use of phosphine with carbon dioxide and heat can reduce the period for fumigating structures.

Potential for fire during application if solid phosphide formulations get wet or are handled carelessly.

Currently available solid formulations generating phosphine gas are not suitable for very dry conditions because of longer time release of gas.

Reacts with and corrodes copper containing materials and chemically similar metals in machinery and ancillary electrical equipment in structures to be fumigated.

Some of these characteristics can be overcome using new phosphine formulations and application practices (see Mueller 2002; Page 74 of these Proceedings).

Other alternatives have limitations such as registration of chemical alternatives, high capital investment for infrastructure and operational costs, lack of country-specific research, lack of technical know-how, technology transfer, activities to sustain adoption, few regulatory and advisory staff and the need for quarantine acceptance of alternatives by the importing countries (TEAP 2001).

MBTOC noted that fumigation with MB could become more frequent in developing countries as a result of developed country phase out and requirements to fumigate before export.

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ALTERNATIVES TO METHYL BROMIDE IN STRAWBERRIES IN SPAIN

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ABSTRACT

Strawberry cultivation consists of mother plant production and plant production for fruit. Since most of the mother plants used in Spain are imported from the United States, it is absolutely essential to understand the applicability of US trends and potential solutions on alternatives to MB for strawberry cultivation in Spain. As result of a four-year research programme in Huelva, several short-term MB alternatives have been developed that include chemical, non-chemical and mixed treatments to meet the requirements of several types of cultivation systems: conventional, integrated pest management and organic production. Adoption of these alternatives by strawberry growers for prolonged and extensive use will depend on EC legislation, consumer responses, scientific explanations for current results, changes to machinary and cultivation practices, and the ability of growers adopt procedures for using new technology.

Keywords: methyl bromide, short /medium-term alternatives, policies, trends, implementation, new compounds.

INTRODUCTION

The ban on the use of methyl bromide (MB) for strawberry cultivation in Spain has very important international and domestic consequences for an agricultural sector divided into two economic, technically and geographically different specialties: plant and fruit production. Plant production is carried out in high-elevation nurseries located in Central-Northern part of Spain (Castile-Leon) mostly dependent on mother-plants obtained from big Californian nurseries. Fruit production is carried out in coastal areas of Huelva, Cadiz, Barcelona, Valencia and other regions using daughter-plants multiplied in the Spanish high-elevation nurseries.

It follows that the alternatives to MB adopted by low and high-elevation Californian nurseries will have a direct influence on the phytosanitary status of plant material multiplied in Spain. In addition, alternatives to MB to be adopted by high-elevation Spanish nurseries will have a direct influence on the status and efficiency of plant material cultivated for fresh fruit production in Spain. Therefore, it is absolutely essential for the development of short-term alternatives to MB for strawberry cultivation in Spain to understand US trends and potential solutions on alternatives to MB, particularly those under development in California and Florida.

Fruit production

Strawberry fruit production is annual (one season) from October until end of May in Huelva. Farm size and grower specialization make it very difficult to alternate strawberries with other crops such as vegetables and/or with fallow periods using cereals.

The main phytosanitary soil-borne problems are *Phytophthora cactorum*, *Verticillium* spp. root-knot nematodes *(M. incognita)* and weeds (in particular yellow nutsedges). However, the most important problems have been grey mould (*Botrytis cinerea*), powdery mildew (*Sphaeroteca macularis*), anthracnose (*Colletotrichum* sp.), two-spotted spider mites (*Tetranychus urticae*) as well as abiotic disorders of fruit malformation during the first part of cropping season. These phytosanitary problems are not related to MB.

Plant production

The cultivation system for plant production is annual (one season) from April until October-December in the area of Castile-Leon. Alternate crops with other cereal and industrial crops (e.g. sugar beet) are possible. It is customary to change location from time to time by means of farm-leasing.

About 95% of the mother plants are imported from big Californian nurseries annually. So far, the general sanitary status of the Spanish nurseries has been satisfactory due to MB fumigation. Main phytosanitary problems are *Phytophthora cactorum*, *Verticillium* spp., *Colletotrichum* sp., phytoplasmas and weeds.

Due to the certification and control system carried out in high-elevation nurseries and the soil fumigation practices and telluric conditions in the area for fruit production, it is difficult to conceive of massive and intense attacks of soil-borne pathogens in Huelva.

QUESTIONS AND REMAINING CHALLENGES

Alternatives under development

As result of a four-year research programme in Huelva (López-Aranda *et al.* 2002), several short-term MB alternatives have been developed for strawberry which have been developed to field demonstration stage. These MB alternatives are chemical, non-chemical and mixed, to fulfill the several types of cultivation systems: conventional, integrated pest management and organic production that require different demands on pesticides utilization. The following possibilities have been established: a) annual shank-application of 1,3 dichloropropene (1,3-D)+chloropicrin (61:35) under pre-formed raised beds (40 cc/m^2 of treated area); (also, shank-application with half-dosage (20 cc/m^2 of treated area) under black VIF sheets; b) annual incorporation of Dazomet located under pre-formed raised beds (50 g/m^2 of treated area); c) soil solarization (4 weeks, August) with simultaneous shank application of metam sodium (75 cc/ m^2 broadcast area); soil solarization (4 weeks, August) with simultaneous biofumigation (fresh chicken manure incorporation, 4-5 kg/ m^2).

These alternatives could be appropriate short and medium-term alternatives to MB where inoculum levels of lethal soil-borne strawberry pathogens are low, as in Huelva. However, there are question marks and remaining challenges for short and mainly medium-term alternatives. How will these alternatives address national and EU policy on pesticides utilization, customer and consumer expectations? What are the scientific explanations for our results? What can we expect from new short-term alternatives yet to be trialled? How will the research results from the National Project INIA be implemented?

Results to date

Shank-application of 1,3-D+chloropicrin (61:35) under pre-formed raised beds has been the best agronomic result as a MB alternative (Telone C-35, Telopic and similar soil fumigants like Agrocelhone). This MB alternative has better potential for future development on strawberry cultivation in Spain than other solutions, particularly for conventional system. However, what will be the future EU policy on (cis or trans) 1,3-D and/or chloropicrin utilization (e.g. Regulation 414). So far, these kind of fumigants have provisional registration and authorization in Spain for strawberries.

On the other hand, soil solarization in combination with biofumigation (simultaneous incorporation of large amounts of organic matter, e.g. chicken manure), is an appropriate alternative solution for integrated crop management and organic production systems. The EU bans the agricultural use of big quantities of livestock manure – will there be a change to this ban? What will be the custumers/consumers response to the use of massive amounts of organic biofumigant for fruit production?

Scientific explanations for our results

Our results and trends, carried out in "steady conditions" of lethal soil-borne pathogens under low inoculum pressure, have shown important morphological and agronomical differences (40-50%) among treatments only two-three years after trials initiation. A single answer that explains the effect of soil-borne pathogen activity, caused by *P. cactorum* and/or Verticillium wilt, is not enough. Our results could also be related to breaking of soil stress phenomena due to physical-chemical soil status (mainly Nitrogen liberation) and/or allelopathic processes and/or with the action of sub-lethal microorganims like black root rot complex (*Pythium* spp., *Rhizoctonia* spp., *Cylindrocarpon* spp.,etc.), and/or the interaction of all these factors. These would be diverse areas to study, but worthy of answers.

Implementation of research results

We have selected shank application as general model system for chemical alternatives (like Telopic, chloropicrin alone, metam sodium, metam potassium and others) in order to take advantage of the whole technology, security protocols, machinery and practical experience obtained from decades of MB use. However, other practical solutions for fumigant application are possible, e.g., pre-planting fumigation with drip irrigation. In the case of strawberry cultivation in California, the best MB alternative carried out has been drip application with InLine (1,3 dichloropropene-chloropicrin 61:35) (Caulkins, pers. com.). In the case of Dazomet as MB alternative, the key factor is to undertake trials to improve localization and incorporation practices, utilization of VIF film technology, and/or combinations with other compounds (e.g. Telopic).

Special equipment (machinery) and procedures have to be improved if solarization is to be used in Huelva. Better still, it may be necessary to introduce new technologies like sprayable plastic polymers for this purpose (Gamliel *et al.* 2001).

Finally, other short and medium-term MB alternatives could be tested under our domestic field conditions: e.g., iodomethane alone or with chloropicrin, sodium azide, propargyl bromide and other products.

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SOIL SOLARIZATION AND BIOFUMIGATION IN STRAWBERRIES IN SPAIN

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ABSTRACT

The use of soil solarization combined with biofumigation resulted in increased soil organic matter content, elimination of an high number of weed species, increased vegetative and productive plant growth in strawberries in Huelva compared with soil solarization alone. The combination treatment requires growers to pay for the plastic sheeting and the costs of its application. Incorporation of chicken manure at 25 tonnes per ha was included at the same time that the soil was tilled when that sheets were removed. The application cost per hectare was about € 850 which was 24% cheaper than shank-applied MB under pre-formed beds.

Keywords: Strawberry, case-study, non-chemical, mixed technique, chicken manure, weed control.

INTRODUCTION

Methyl bromide (MB) has been used as soil fumigant for soil-borne pathogens and weeds since World War II. Its applications in strawberry cultivation started in California during the 1950's. MB soil fumigation practices in Spain were imported from California by highly specialized pioneers (farmers and agronomists) located in Andalusia, during the 1960's, along with the new technology for strawberry production using new plant varieties. MB is due to be phased out by 2005 following the requirements of the Montreal Protocol (see Bolivar 2002) and the European legilsation (see Batchelor 2002). About 33% of the MB in 1995 in Spain was used for strawberry cultivation.

Soil solarization and biofumigation are some of the short-term, non-chemical alternatives suggested for strawberry cultivation which are described more fully below. The fumigants 1,3- dichloropropene-chloropicrin, dazomet and metam sodium are considered short-term chemical alternatives to MB. Some of them e.g. metam sodium, can be used in combination with soil solarization or shank-applied under VIF plastic sheets. All these options have been examined in the Spanish National Project INIA SC 97-130 "Alternatives to the conventional use of MB environmentally safe and in a cost effective manner". The results support a 75% reduction in MB consumption in 2003 on strawberry cultivation, and that short-term alternatives for Huelva's strawberry production exist (López-Aranda et al. 2000).

SOIL SOLARIZATION

Soil solarization is an easy disinfection technique based on the use of soil heating, due to the solar radiation during summer, that elevates soil temperature (at field capacity of water content) in a field previously covered with transparent polyethylene (PE) sheeting. Elevated soil temperatures are reported to be lethal or sub-lethal for soil-borne pathogens and weeds (Katan 1981). This method of soil disinfection is less effective on mobile organisms like root-knot nematode that are able to more away to cooler soil temperatures during periods of solarization. Soil solarization is also reported to be more effective in soils that have a high organic matter content. Combining solarization with reduced dose of chemical fumigants such as metam sodium (75-100 cc/m^2) achieved similar results to MB (López-Aranda *et al.* 2000).

BIOFUMIGATION

Biofumigation uses gases and other products from organic amendments and residue biodegradation as fumigants against soil-borne pathogens (Bello *et al.* 1999). Biofumigant materials include livestock manure, refuse from the waste paperbin, fishing factory waste, numerous agricultural and food industrial waste, as well as plant residuals with allelopathic compounds (Hoitink 1988). Nitrogen compounds (like ammonium and nitrates), organic acids and a great number of volatile substances are responsible for this biocidal activity (Mian *et al.* 1982).

SOIL SOLARIZATION AND BIOFUMIGATION

Katan (1981) suggested that organic residuals incorporation into the soil could increase the effectiveness of solarization. Lacasa *et al.* (1999) showed that biofumigation applied in combination with solarization between July to October is effective for controlling soil-borne pathogens. Solarization is recommended for 30-45 days during the months when the soil temperatures exceed 50ºC, although when combined with biofumigation, the soil temperature could be as low as 40ºC. As a negative effect, it is necessary to point out that soil biodiversity losses have been observed.

SOIL SOLARIZATION AND BIOFUMIGATION IN STRAWBERRIES IN HUELVA

As consequence of the first results found out by the Spanish National Project INIA SC 97-130, soil solarization in combination with biofumigation was applied in plots dedicated to strawberry cultivation at the Experimental Farm "El Cebollar" (Moguer, Huelva). These plots were never fumigated and began to be cultivated with strawberry from 1992 without any soil disinfestation practice.

Six to seven weeks of solarization, from the first half of July until the beginning September, were carried out annually each summer from 1995 to 1998. From July 1999, chicken manure was applied before application of the solarization film. Chicken manure dose were about 25 tonnes/ha, less than those utilized by Huelva's farmers. Before the organic amendment incorporation, the soil was sprinkler irrigated until the field capacity of the water content was attained. After the chicken manure was incorporated, the soil was covered with transparent sheets by means of a prototype machine designed using funds from the National Project INIA SC 97-130. The polyethylene (PE) sheets were 50 microns thick and 3.30 m wide. This kind of plastic was the same as the one utilized for traditional broadcast of MB shank-application in the area. Soil strips of 40-50 cm wide remained without disinfestation among the PE sheets. Plastic sheets were removed after 6-7 weeks (beginning of September) and then harrow passes were given to improve soil homogeneity. The same solarization/biofumigation practices have been repeated in the summers of 2000 and 2001.

The use of soil solarization combined with biofumigation has resulted in the following improvements at our Experimental Farm: a) Increased soil organic matter content; b) Elimination of an high number of weed species (in particular purslane, *Portulaca oleracea,* very frequent in the summer time); c) Increased vegetative and productive plant growth compared with soil solarization alone (13% of yield increasing last 2001 season in cv. "Camarosa"). The combination treatment requires growers to pay for the plastic sheeting and the costs of its application. Incorporation of chicken manure at a similar dosage was included at the same time that the soil was tilled when that sheets were removed. The application cost per hectare is about € 850 which is a 24% cost reduction in comparison with shank-applied MB under pre-formed beds (€ 1,120).

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CASE STUDY: *TRICHODERMA* AS AN ALTERNATIVE TO METHYL BROMIDE IN STRAWBERRIES

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ABSTRACT

Trichoderma is known for being the most used biocontrol agent in Agriculture. Most of the isolates of the genus *Trichoderma* that have been found to act as mycoparasites of many economically important aerial and soil-borne plant pathogens. Phasing out methyl bromide (MB) will have a disproportionate effect on southern European emerging economies, and will increase dependence on chemical control measures. An EU-funded project aims to develop integrated biological, physical and low-chemical approaches to strawberry crop protection based on naturally occurring strains of *Trichoderma* active against the principal fungal pathogens *Collelotrichum*, *Phytophthora* and *Botrytis*, and to find strains of *Trichoderma* active with solarization. For postharvest treatments, novel biocides will be extracted from *Trlchoderma* proteins to determine their potential for protecting the strawberry fruit from pre- and post-harvest diseases. Synergistic effects of the various control measures developed will be explored in an effort to recommend integrated strategies for strawberry production with minimal chemical input.

Keywords: Biocontrol, *Trichoderma*, cell wall degrading enzymes, solarization, IPM.

INTRODUCTION

Trichoderma is known for being the most used biocontrol agent in Agriculture. Most of the isolates of the genus *Trichoderma* that have been found to act as mycoparasites of many economically important aerial and soil-borne plant pathogens (Chet 1987), have been classified as *T. harzianum* Rifai. This leads to the fact that the species *harzianum* is generally considered as a mycoparasite and synonymized as a " biocontrol agent". However, the taxonomic status of *T. harzianum* has been unclear for a long time, as Rifai (1969) and Bissett (1991) used different concepts for its definition.

We have recently described (Hermosa *et al.* 2000) the presence of at least four different species – *T. harzianum s.str., T. atroviride, T. longibrachiatum* and *T. asperellum* within biocontrol isolates identified as "*T. harzianum*". The combination of these species in the same formulation facilitates their effectiveness to colonize soils and protect plants against their pathogens.

Trichoderma spp. evolve numerous mechanisms for both attacking other fungi and enhancing plant and root growth. Several new general methods for both biocontrol and plant growth promotion have recently been demonstrated and it is now clear that there must be hundreds of separate genes and gene products involved in these processes, including mycoparasitism, antibiosis, competition for nutrients or space, tolerance to stress through enhanced root and plant development, solubilization and sequestration of inorganic nutrients, induced resistance and inactivation of the pathogen's enzymes (Monte 2001).

A few of these genes have been patented and used for plant transformation (Lorito *et al.* 1998), and they are in the process of reaching the market, but new sets of novel genes are being developed for their biotechnological application. In addition, *Trichoderma* strains have beneficial effects in agricultural systems other than pathogen control, principally through increasing soil fertility by active breakdown of organic matter. All these features facilitate the use of *Trichoderma*, at different levels, as an alternative to soil fumigants against plant pathogenic fungi.

Phasing out methyl bromide (MB) will have a disproportionate effect on southern European emerging economies, and will increase dependence on chemical control measures. Strawberry crops in California are predicted to decline by 25% without MB and similar reductions may be expected in Mediterranean countries where strawberries are farmed intensively on US-style models. MB is used as a soil sterilant before planting in polythene tube systems and is effective for controlling nematodes, soil insects, weeds and fungi. However, the non-specific action of MB destroys natural, microbiologically-mediated disease suppression in the soil and can facilitate rapid recolonization by pathogens.

PROJECT DESCRIPTION

We are working in a EU-funded project (FAIR6-CT98-4140) to develop integrated biological, physical and low-chemical approaches to strawberry crop protection. Our aims are a) To promote natural, biological, physical and low-chemical control strategies for fungal pathogens as alternatives to MB and chemical fungicides in European strawberry cropping systems by developing consumer- and environment-low risk altenatives; b) To select naturally occurring strains of *Trichoderma* active against the principal fungal pathogens *Collelotrichum*, *Phytophthora* and *Botrytis*, and to explore their use alone and in combination with other targeted methods in laboratory and field conditions; c) To assess the efficacy and survival of selected *Trichoderma* strains in conjunction with solarization techniques, and to investigate the effects of their application to beneficial soil organisms; d) To develop novel biocides from *Trlchoderma* proteins to protect the strawberry fruit from pre- and post-harvest diseases (Figure 1); and e) To explore the synergistic effects of the various control measures developed, and to recommend integrated strategies for strawberry production with minimal chemical input.

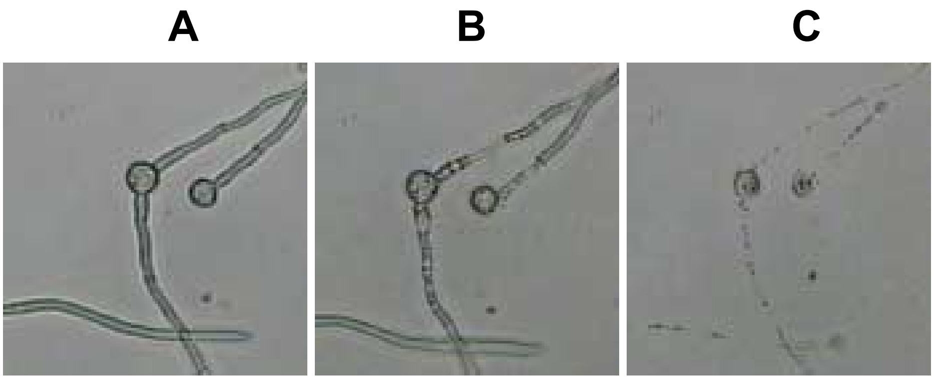

Figure 1: Detailed microscope image of *T. harzianum* 9.3 action on *B. cinerea* hyphae at 0 (A), 30 min (B) and 7 hours (C) after culture filtrate addition.

There are three major novel strands in this project, involving synergies between different control measures. Firstly, combinations of selected (but not genetically modified) *Trichoderma* strains are being explored as soil and foliar additives, in order to increase the effectiveness and range of pathogen control. Secondly, biocontrol strains are integrated with solarization techniques for partial soil sterilization and further colonization with highly competitive and beneficial fungi. Selected *Trichoderma* strains are compatible with solarization preferentially, allowing the maintenance of permanent pathogen-antagonistic soil systems. Thirdly, the combination of traditional *Trichoderma* biocontrol systems with novel antifungal agents derived from *Trichoderma* enzymes which are being tested as environmentally friendly foliar sprays or post-harvest treatments. As a result, one of the *Trichoderma* cell wall degrading enzyme genes is being used to transform strawberry plants.

We have also investigated the synergies of biocontrol organisms and their products with minimal doses of chemical control agents to develop protocols which maximize control but minimize inputs. The consortium has identified and promoted optimal control systems using components from our IPM spectrum, which should result in effective control of strawberry diseases on a long-term sustainable basis. The experimental processes will act as a model for developing environmentally friendly control measures for pests and pathogens of other MB-dependent crops.

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SODIUM AZIDE FOR SOIL PEST CONTROL IN CROPS WITH FEW OR NO ALTERNATIVES TO FUMIGATION WITH METHYL BROMIDE

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ABSTRACT

Stabilized liquid formulations of sodium azide (NaN_3) can be a “one-to-one” substitute for methyl bromide (MB) in horticultural crops. NaN_3 can be delivered through irrigation water and does not need specialized equipment for application to the soil. Greenhouse, microplot and field studies at Auburn University demonstrated that the chemical is directly toxic to nematodes, weeds, and soilborne fungal pathogens that cause vascular wilts, root rots and damping off. NaN_3 is particularly effective against purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentum*), Carolina geranium (*Geranium carolinianum*), bur clover (*Medicago* spp.), and other weeds that are very difficult to control. Previous long-term studies at Auburn University showed that soils treated with NaN_3 are enriched with beneficial fungi (*Gliocladium, Trichoderma*) species of which are major antagonists of the southern blight pathogen (*Sclerotium rolfsii*) and damping off fungi (*Rhizoctonia, Pythium, Fusarium*).

keywords: azides, inorganic azides, herbicide, horticultural crops, hydrazoic acid, nematicide, root-knot nematodes, sodium azide, soil fumigation, strawberry, weed control.

INTRODUCTION

Na and K azides are salts of hydrazoic acid (HN_3) that have been explored in a limited manner for their pest controlling properties in the past. These materials are solids, readily soluble in water, and can be formulated as granules or liquids. Azides are potent metabolic inhibitors affecting the activities of a variety of oxidative enzymes, notably those involved in the electron transport system of respiration. There is ample information on the toxicological properties of sodium and potassium azides on humans (TOXLINE 2001).

These compounds are hypotensors (Merck Index 1989) and were used in the 1950's for treatment of certain types of cancers in humans and more recently in formulations to fight AIDS. Extensive studies have demonstrated that azides are not carcinogenic. Currently, sodium azide (NaN_3) is used principally by the auto industry in air bags. While azides of heavy metals such as Cu, Pb, Hg, are unstable and explosive, those of sodium and potassium are considered safe and stable under ordinary conditions (Moeller 1952).

Sodium and potassium azides when added to soils (pH<7.0) release HN_3 which is converted chemically by reaction with water to NH_4^+ and to nitrate through the action of nitrifying bacteria (Parochetti & Warren 1970).

Field research at Auburn University in the 1970's in a commercial pine nursery and with several row crops showed that granular formulations of sodium and potassium azides applied to soil demonstrated broad spectrum activity against weeds, nematodes, and soilborne phytopathogenic fungi (Kelley & Rodríguez-Kábana 1979b; Rodríguez-Kábana & Robertson, 2000; Rodríguez-Kábana *et al.* 1975; Rodríguez-Kábana *et al.* 1972). Similar results were obtained in other areas of the U.S. and in Belgium with high-value horticultural crops (van Wambeke *et al.* 1984, 1985; van Wambeke & van den Abeele 1983). Microbiological studies of soils treated with NaN_3 for several years indicated that, in contrast to MB-fumigated soils, those treated with azide showed increased population levels of a group of fungi (principally species of *Trichoderma* and *Gliocladium*) antagonistic to a broad spectrum of soilborne phytopathogenic fungi (Kelley & Rodríguez-Kábana, 1975, 1979a, 1981). The mode of action of sodium and potassium on soil-borne pathogens is based on short-term direct toxicity, but may also involve as yet undetermined long-term effects through enrichment of the soil with microbial species antagonistic to the pathogens.

Sodium and potassiuum azides can be formulated as granules (attapulgite clay, diatomaceous earth) or in a variety of liquid formulations. Key to the stability of these formulations is that the pH remains greater than 9.00. This can be accomplished for granular formulations by including sufficient sodium and potassiuum carbonate to buffer the granules at pH 9.5 - 10.0. Granular formulations were used to control weeds and soil-borne pests typically located in the top 7 - 10 cm of the soil profile. However, for other pests (nematodes, *Armillaria, Verticillium*) and deep-rooted crops (grapes, fruit, and nut trees), liquid formulations are more suitable. Delivery of azide to the desired fumigation zone may be difficult if reactivity of HN_3 in the soil-air space and atmosphere is too rapid and results in a concentration of the active compound too low for effective pest control. One way to achieve a more uniform distribution of the chemical might be to apply the chemical through a drip irrigation line. Recent work at Auburn University demonstrated the feasibility of preparing liquid formulations of sodium and potassiuum azide suitable for delivery through drip irrigation systems.

Preliminary fieldwork indicates that sodium and potassiuum azides possess considerable flexibility for preparation of formulations suitable for specific crops and situations. The activity of this material is influenced by soil pH. The optimal application method in the alkaline soils is different from that best suited for acid soils. The generally favourable properties of NaN_3 as a potential substitute for MB prompted the Nematology team at Auburn University to conduct research to develop new formulations for field use of the compound and to evaluate NaN_3 as an alternative to MB for control of nematodes, weeds, and pathogens in high-value cropping systems.

MATERIALS AND METHODS

Microplot Experiments. Microplot trials were conducted on the Auburn University's campus microplot facilities to determine the efficacy of new experimental formulations for NaN_3 as a MB alternative. A microplot consists of a one-ft^2 (929 cm^2) area delimited by a *terra cotta* chimney liner (2.54 cm- thick wall) embedded 41 cms deep into the soil and protruding 2 cms above the soil. Soil in the microplots were loamy sands with pH = 6.2, organic matter content <1.0%, and cation exchange capacity < 10 meq/100 g soil. The soils are typical for Alabama and are infested with a variety of plant parasitic nematodes including root-knot nematodes (*M. arenaria, M. incognita,* and species of *Helicotylenchus, Hoplolaimus, Paratrichodorus, and Pratylenchus*), southern blight (*S. rolfsii*), and typical damping off (*Rhizoctonia, Pythium*) and wilt (*Fusarium, Neocosmospora*) pathogens. The microplots were infested with nutsedge (*Cyperus esculentum* & *C. rotundus*) and other weeds which, in combination with the other pests present in the soil, represented closely the problems faced by producers in fields requiring fumigation with MB.

In a typical experiment, NaN_3 was applied at rates in the range of 25 - 300 kg ai/acre using various formulations. The treated soil was covered with standard polyethylene plastic for two weeks, after which the plastic was removed and crops (eggplant, tomato, or okra (*Abelmoschus esculentum*)) were planted. Each crop was grown in accordance with standard commercial practices. Treatments in each trial were arranged in a randomized complete block design with eight replications per treatment. Variables studied in the experiments were pest population densities (weeds, nematode numbers, disease incidence), crop growth parameters, phytotoxicity, yield, and product quality. Data were analyzed using standard statistical methods, primarily Analysis of Variance (ANOVA).

Field Experiments. A strawberry trial was conducted in the 2000 season near Plant City, Florida, in a sandy field infested with the sting nematode, yellow nutsedge and other weeds. Plots were 200 meters long and NaN_3 (preplant at 100 Kgs/Ha) was compared with MB at 400 kg/ha. The azide was applied through the drip irrigation system (2 tapes/bed) in enough water to penetrate the soil profile to a 45-cm depth. In 2001, a strawberry trial was established in a field at the Auburn University's Experiment Substation, near Brewton, Alabama. NaN_3 was applied preplant at 150 kg/ha as described for the Florida experiment. In both experiments, data were collected on nematode and weed populations and on yield.

RESULTS

Data obtained from microplot experiments indicate that Na azide is a potent nematicide effective for controlling root-knot nematodes (*Meloidogyne* spp.) and many other nematodes important in eggplant, tomato, green pepper, strawberry , tomato and other high value crops. The compound must be used pre-plant with a 7-10 day wait period before planting. Although Na azide does not require plastic cover after application to soil its performance is considerably enhanced by covering the soil (Figures 1a, 1b and 1c).

Field experiments with strawberry conducted in Florida and Alabama in 2000 and 2001 demonstrated that pre-plant applications of Na azide at rates of 100-150 Kgs/Ha eliminated weed and nematode problems and was equal or superior to MB in yield response.

CONCLUSIONS

Data from microplot and field experiments indicate that NaN_3 can be applied easily by drenching or through drip irrigation systems without need of special equipment or exposure to workers. The pre-plant wait period required is similar to that for MB and well within the logistical requirements for crop production. Sodium azide applications in the range of 80 - 150 kg/ha are optimal for control of nematodes, weeds and other soil-borne pests. These rates are economical and compare favorably with MB.

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FIGURES

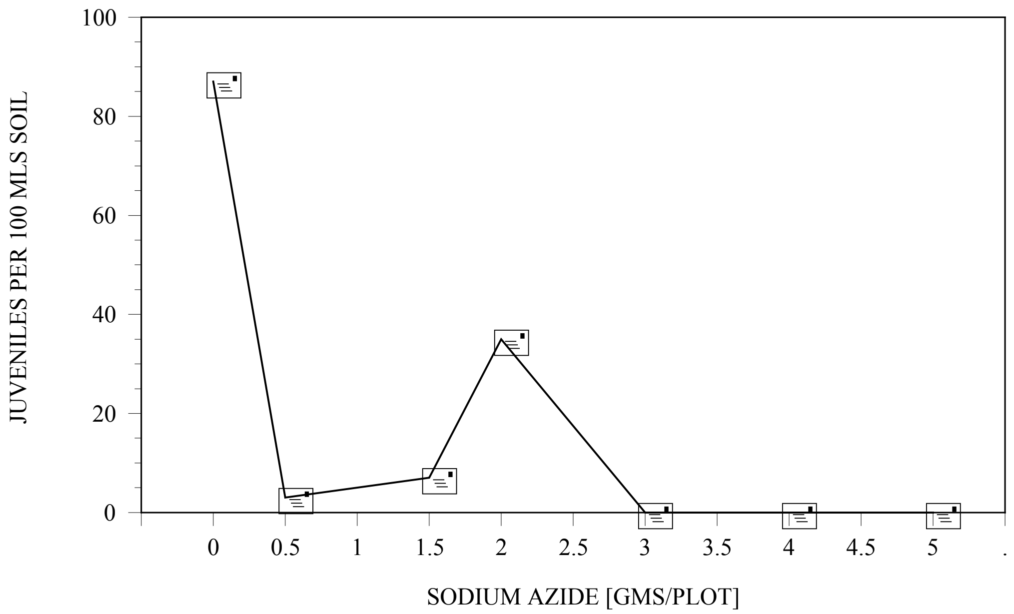

Fig. 1A. Effect of preplant applications of sodium azide on final populations of the root-knot nematode Meloidogyne incognita in a microplot experiment with ‘Black Beauty’ eggplant (1 g/plot is equivalent to 100 kg/ha).

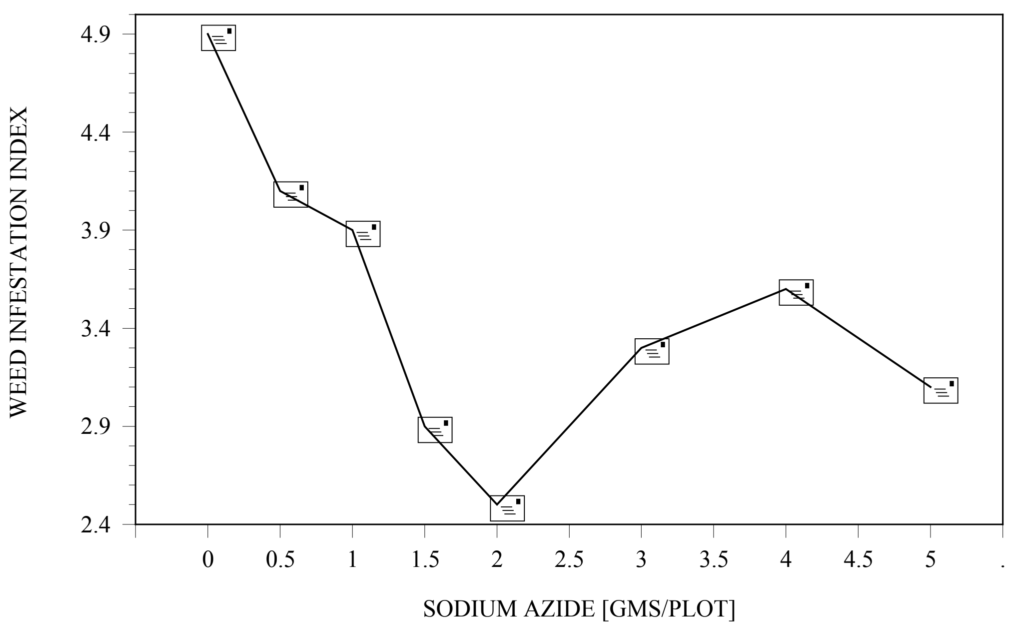

Fig. 1B. Effect of preplant applications of sodium azide on weed populations in a microplot experiment with ‘Black Beauty’ eggplant. Index scale: 1= no weeds to 5= plot completely covered with weeds.The principal weed species were yellow nutsedge *C. esculentum* and crabgrass *Digitaria sanguinalis*.

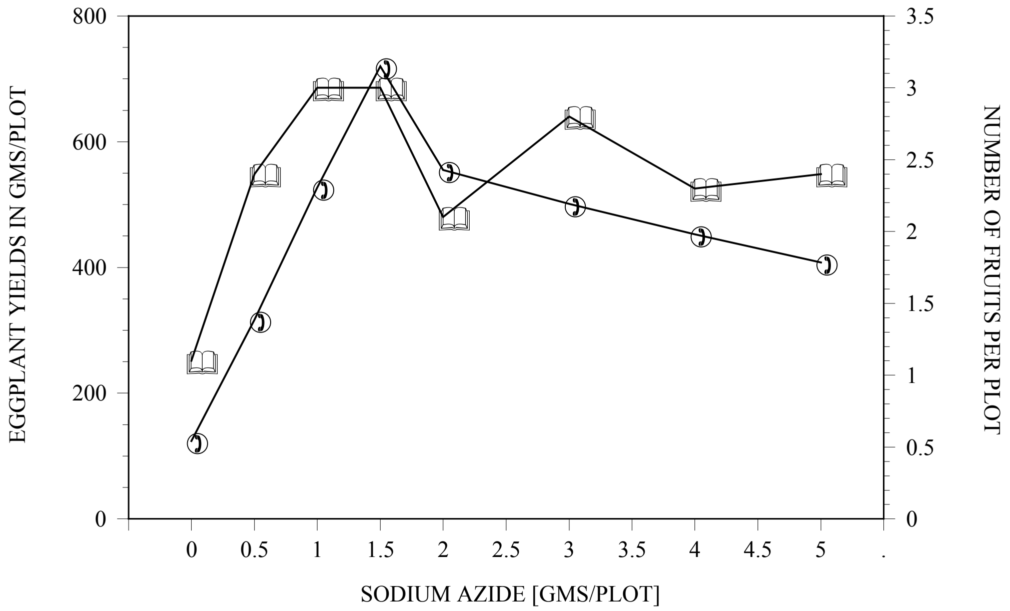

Fig. 1C. Effect of preplant applications of sodium azide on number of fruits [diamonds] and yield (circles) in a microplot experiment with 'Black Beauty' eggplant.

SPANISH STRAWBERRY PLANT NURSERIES AND THE USE OF METHYL BROMIDE AS A SOIL DISINFECTANT

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ABSTRACT

Methyl bromide (MB) with chloropicrin has been used in strawberry production in Spain since the 1980s and is effective for controlling fungal pathogens, nematodes and weeds. Increased production in recent times has been accompanied by the need to increase phytosanitary quality. In the 1990s, the development of high-elevation nurseries located in region with suitable soils and climate resulted in increased production that was linked to disinfection using MB. This combination led to Spain being confirmed as the main strawberry plant producer in terms of quality and quantity after the United States of America. Over the last five years, the nursery sector has cut MB use from 446 tonnes in 1997 to 190 tonnes in 2001 which reflects a real 42.6% reduction in the use of MB. At the present time, MB is the most important working tool available enabling strawberry plant nursery operators to produce strawberry plants with sufficient phytosanitary quality and guarantees. The continued use of MB is requested after 2005 at least for nurseries as MB is critical for the whole strawberry-growing sector, not only because of its importance at the initial stage in the nurseries but also because of the repercussions that a prohibition on its use in nurseries would have on the fruit-producing areas.

Keywords: methyl bromide, alternatives, nurseries, phytosanitary, weeds, pathogens

INTRODUCTION

A number of strawberry plant varieties have been grown in Spain for more than thirty years. The sector grew rapidly from the mid-1980s, which resulted in strawberry plant cultivation in nurseries on irrigated land increasing up to 1 000 hectares.

Methyl Bromide (MB) has been used as a soil disinfectant since the 1980s. As it was also effective in combating weeds, within a few years of being introduced it had taken the place of other products such as metam sodium and metam potassium which were much less effective in controlling fungal pathogens, nematodes and weeds. The accepted application was 600 kg of a 98:2 mixture of MB and chloropicrin per hectare.

The introduction of the use of MB led to increased production per hectare: 250 000 – 300 000 for the Tioga variety, 400 000 for Douglas and 450 000 – 500 000 plants per hectare for Chandler, the variety whose use of MB became an established and widespread practice. Increased production was accompanied by increased phytosanitary quality, cutting to a minimum the incidence of diseases such as *Phytophtora* sp., *Verticilium* sp., *Rhizoctoria* sp., and nematodes such as *Melodoigyne* sp. and *Aphellenchoides* sp., which were formerly real scourges, not only causing serious damage in nurseries but also causing growers considerable economic problems in the fruit-growing areas where plants carrying the inoculum were sent.

Finally, there was less time spent on weed control which further increased the economic return from the crop.

In the 1990s, the development of high-elevation nursery techniques, the increased professionalism of commercial nurseries, the suitability of the soil and climate, and of course soil disinfection using MB, led to Spain's position being confirmed as the main strawberry plant producer in terms of quality and quantity after the United States of America.

CURRENT SITUATION

In 1997, 800 hectares of strawberry plants were grown in Spain, 95% of which were disinfected using a 98:2 mixture of MB and chloropicrin at a rate of 600 kg per hectare, making a total of approximately 446 tonnes of MB used overall in nurseries.

In 1998 and 1999, the mixture was diluted for the first time to 67:33 with a reduction in the application from 600 to 400 kg per hectare. The same period saw the land area dedicated to the crop increase to 950 hectares. Approximately 242 tonnes of MB were used in nurseries.

In 2000 and 2001, the mixture was diluted further, with a 50:50 mix being widely used, and the number of hectares cultivated rose to 1000, 950 hectares of which were disinfected with an application of MB at 400 kg per hectare. Approximately 190 tonnes of MB were therefore used in nurseries annually.

To sum up, over the last five years, the nursery sector overall has cut MB use from 446 tonnes in 1997 to 190 tonnes in 2001. This reflects a real 42.6% reduction in the use of MB, indicating the sector's commitment to cutting down on the product while optimising its efficiency.

FUTURE PROSPECTS

Faced with no imported or produced MB being permitted to be and placed on the European Community market for soil fumigation from 1 January 2005, the Spanish association of strawberry plant nurseries (*Asociación Española de Viveristas de Planta de Fresa* - AEVPF), has taken part in the Spanish project to find alternatives to MB since 1998. The following results of that project should be highlighted:

1. When land which has not been disinfected previously is used, only chloropicrin-based alternatives have any real disinfectant effect and even these do not control weeds sufficiently.
2. In the crop cycle for a nursery disinfected with 400 kg of a 50:50 MB/chloropicrin mixture per hectare the average time spent on weed control is 20 days per hectare. The cost increases to 26 days if chloropicrin with Telone is used and up to 38 days if solutions such as Metam sodium or Metam potassium are used. This entails a 90% increase in the costs of manpower which is already in itself scarce and expensive.
3. The volume of production in terms of the number of saleable plants per hectare in some cases has fallen to 30%.
4. The phytosanitary quality of the plant is considerably reduced, causing sites of vascular disease to emerge requiring increased manual treatment and increased application of fungicides and pesticides. This brings about a greater incidence of resistant pathogen strains which are ever more aggressive and difficult to control in nurseries and also entails increased production costs and a reduced volume of production.
5. Since this is a crop where phytosanitary quality must be officially certified, prohibition of the use of MB as a soil disinfectant would mean that every year a large number of plots of ground could not be certified and to a certain extent it would cease to be viable to export such plants since their health could not be guaranteed.

CONCLUSIONS

There is no escaping the conclusion that, without effective disinfestation, nurseries would be responsible for transferring increasingly aggressive pathogen strains to growing areas along with the plants. These areas would then carry the inoculum but would have increasing limited means of defence, given that pest-control treatments in fruit-growing areas are increasingly hazardous in view of the residual - and occasionally lethal - nature of the active substances in the fruit, the trend towards integrated production crops (IPM) where the use of such active substances is prevented and limited, the increased sensitivity of consumers and the relevant legislation in force in the countries of Europe which is increasingly exacting and restrictive.

At the present time, MB is the most important working tool available enabling strawberry plant nursery operators to produce strawberry plants with sufficient phytosanitary quality and guarantees.

None of the alternatives currently being investigated is a reliable substitute for MB in nurseries as they:

- Increase the costs of soil disinfection per hectare;
- Increase the manpower costs for weed control;

- Increase the costs of cleaning and spraying with active substances;
- They do not guarantee plant health or the consequent successful certification of plants

The greatest risk is undoubtedly the spread of pathogens to fruit-producing areas, multiplying the economic impact we have already noted for nursery areas, since a single hectare of nursery produces enough plants for approximately 10 hectares of fruit crops.

In the light of the above, we consider MB to be key to the stability of strawberry growing and therefore request that its continued use be authorised at least for nurseries, since it is critical for the whole strawberry-growing sector, not only because of its importance at the initial stage in the nurseries but also because of the repercussions that prohibiting its use in nurseries would have on fruit-producing areas. MB use should therefore be maintained in nurseries in order to safeguard the health of strawberry crops from the very first stages.

STRAWBERRY PRODUCTION AND THE USE OF ALTERNATIVES TO METHYL BROMIDE IN HUELVA (SPAIN)

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ABSTRACT

The cultivation of strawberries in Huelva has had to overcome a gradual decrease in initial profitability by increasing yield. This has necessitated the use of soil fumigants, especially MB. The reduction requirement in the use of MB imposed by Regulation EC 2037/00 and the Protocol of Montreal have been rigorously followed, while maintaining profitable cultivation, using novel techniques (such as shank-applications under preformed beds only, VIF film utilization, and others) and also by reducting the MB percentage in MB-PIC commercial formulations. The Spanish National Project on short term MB alternatives allows growers to be, according to initial data, optimistic that short term chemical alternatives will be ready. Nevertheless, these solutions will have to assure cost effective production. There remains some doubt on the availability of alternatives for the medium and long term. According to the reports so far, the availability of healthy plant material from our high-elevation nurseries with intact agronomic potential and at a reasonable cost is not at all guaranteed without the use of MB. For this reason, the strawberry sector thinks it is of utmost importance to use MB and consequently requests Critical Use authorisation for the continued use of MB in Spanish high-elevation nurseries after 2005.

Keywords: strawberry, Huelva area, fruit production, nurseries, Methyl Bromide, productivity, alternatives, future perspectives, critical uses.

INTRODUCTION

An analysis of the potential impact of the unavailability of methyl bromide (MB) for strawberry production in the area of Huelva should be carried out taking into account the evolution of costs in the cultivation of strawberries and expectations of the crop's continued economic viability.

Strawberry cultivation in the area of Huelva has maintained profitability from the beginning of the 1980's when today's production practices were put in place. Nevertheless, the strawberry sector has been confronted, season after season, with a constantly growing curve of production costs. The costs have were due particularly to labour costs. This situation combined with static or even decreasing market values for fresh strawberries in the European and National markets has been so far solved by growers increasing overall yield. Based on the need to continue this level of economic activity that generates more than 60,000 direct jobs and more than 4.5 million day's work per year in the area of Huelva, the strawberry industry must have all the keys to allow it produce to its full potential.

The results of the Project of High National Interest (INIA) "Alternatives to the Conventional Use of MB Environmentally Safe and in a Cost Effective Manner", in which our strawberry Professional Organization (Freshuelva) has been collaborating from their beginning, clearly demonstrated the dramatic drop in yield when no treatments are used against soilborne problems. Productivity in non-fumigated controls could decline by as much as 40%, even in absence of lethal strawberry soilborne pathogens. This phenomenon could be possibly attributed to soil stress and/or sub-lethal microorganism activity. For this reason, the strawberry cultivation system in Huelva has been traditionally developed with the use of soil fumigants, generally MB, in order to ensure levels of productivity (unitary yields) and consequently adequate profitability for this crop (López-Aranda *et al.*, 2000, 2001a, 2001b).

The new situation due to the Montreal Protocol guidelines has created special problems that our strawberry growers, acting as pioneers in the world, have solved with strong discipline by means of technical novelties such as shank applications under pre-formed beds only, combinations of MB-Pic with decreasing amounts of MB formulation, VIF film technology utilization, and other treatments. These new technologies have allowed them to comply with the gradual MB reductions imposed by the

European Commission Regulation EC 2037/00, in agreement with the Montreal Protocol. In the case of strawberry in Huelva, MB doses have been reduced by about 80% compared to the 1980's which is without precedent in intensive agriculture in Mediterranean conditions.

Meanwhile, an appropriate answer from our Public Administrations to the anxious strawberry sector wishing to comply with the regulations, acting with a much wider perspective to preserve the environment but at the same time very worried by the potential elimination of a decisive element for the viability of the cultivation, the mentioned INIA Project started to find short-term alternatives that could merge environmental safety with the survival of a large agrarian economic and social activity found in strawberry cultivation in Huelva. For that, we would like to choose this particular occasion to transfer to sincerely thank the whole scientific team of this Project and very especially Dr. López-Aranda on behalf of the strawberry growers of Huelva for their invaluable services.

With the normal caution in these kind of situations and still in a provisional context, the well-known Project data so far (López-Aranda *et al.* 2000, 2001a, 2001b) allowed a certain trust to be maintained in the chemical short term alternatives to MB. Technically viable and cost-effective alternatives will be received with interest by growers and without a doubt they could be practiced once they will acquire the knowledge to use them.

We think that the aim of this case-study is not to carry out a rigorous technical analysis of the new MB short-term alternatives that are beginning to be defined as these must be formally presented to the strawberry sector by the scientific team of this National Project. Nevertheless, we repeat, these alternatives to be considered as technically viable, and would have to have the same statistical significance of effectiveness as MB. Otherwise, growers could be expected to accept a decrease in strawberry production in the area. This possibility would have to be evaluated carefully by the strawberry growers and to decide if they are able to accept such a production decrease.

Strawberry high-elevation nurseries is a specific topic of other papers submitted in this International Conference. For this reason, we are not going to consider it with detail. Nevertheless, it is an important factor for the viability of our southern strawberry cultivations. Due to the necessity of plant material with a good phytosanitary status, with all full agronomic potential and at a reasonable price.

It is possible to define as very difficult the situation in the Spanish high-elevation nurseries taking account the results so far of the activities of National Project INIA developed in Castile-Leon and its consequences for fruit production in our area. According to those trends (*Melgarejo et al.* 2001), the availability of healthy plant material with full agronomic potential at a reasonable price is not at all guaranteed in absence of fumigation with MB in these high-elevation nurseries. For this reason, unfortunately, and on the contrary that we have expressed regarding the fruit production situation, in this Conference and on behalf of the survival of the strawberry cultivation in the area of Huelva, we claim as indispensable the concession of the Critical Uses for MB utilization in the case of Spanish strawberry high-elevation nurseries.

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NON-METHYL BROMIDE QUARANTINE AND PRE-SHIPMENT TREATMENTS IN SPAIN

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ABSTRACT

The use of fumigants, especially methyl bromide (MB), is practical and economical method to eradicate pests from horticultural commodities in quarantine treatments. Only a minor number of imports e.g. treatments of oak log or wood packages from conifers that have not been treated at origin, and a minor number of our exports e.g. garlic destined to Brazil and chestnut to Mexico, receive quarantine treatments with MB in Spain. Quarantine treatments in Spain consumed in recent years 5-6 tonnes per year for these purposes. Banning MB has encouraged the search for alternative procedures. In wood imports, fumigation with MB has been substituted by mechanical methods such as debarking or by physical methods such as heat treatments. Phosphine and fog systems of aqueous solutions of phosphorate products have substituted for MB in pre-shipment treatments for export grain (cereals and leguminous) and the equipment that carry these exports. Cold treatments have been used in fruit exports to countries that require a quarantine treatment for fruit fly *Ceratitis capitata* (Wiedeman).

Keywords: Spain, quarantine treatments, import, exports, pre-shipment, methyl bromide

INTRODUCTION

Submitting horticultural commodities to quarantine treatments is surrounded by an number of serious concerns such as the treatments may not as efficacious and as convenient as methyl bromide (MB) and because the cost of application is borne by the country of export.

Chemical treatments with fumigants are a practical and convenient way to eradicate pests in crops and vegetable products. Several aspects favour their use. Fumigants kill a broad range of pests, they are economic and easy to apply in different types of facilities, lorries, railcars or ship holds, or fumigation facilities can be inexpensively built. In addition, treatments can be applied in a short time, usually in a few hours.

However, fumigants are not free from inconvenience. Their extreme toxicity to humans for some fumigants requires some security measures to be taken to protect fumigant applicators and handlers from the treated commodities. Consumers perceive that residues of fumigants on fresh products constitute a high health risk. This perception has been recognised in the regulations of different countries that establishes low Acceptance Residue Levels (ARL) or has banned the use of some fumigants. This limits or restricts the use of specific fumigants on vegetable products destined for certain markets.

Only a minor number of imports e.g. treatments of oak log or wood packages from conifers that have not been treated at origin, and a minor number of our exports e.g. garlic destined to Brazil and chestnut to Mexico, receive quarantine treatments with MB. Quarantine treatments in Spain consumed in recent years 5-6 tonnes per year for these purposes.

The banning of use of ethylene dibromide due to its carcinogenic effects, and the limitation of use of MB due to its negative environmental effects, requires the search for alternative treatments to MB.

QUARANTINE TREATMENTS IN SPAIN

Quarantine treatments used in Spain are divided into those required for import and those required for export that are required by the importing country.

Imports

The required treatments are listed in Directive 2000/29/CEE and in the Spanish legislation RD 2071/1973 and its later modifications. The liberal policy of EU has reduced these treatments very much and limited them to the treatment of wood and citrus from certain countries and when certain conditions are given.

In wood, required treatments are mechanical methods such as debarking and/or physical methods such as heat treatments. Wood of conifers (Coniferales) except of *Thuja* originating in Canada, China, Japan, Korea, Taiwan and the USA must be treated by an appropriate heat treatment (HT) to achieve a minimum wood core temperature of 56ºC for 30 minutes. Wood conifers originating in non-European countries other than Canada, China, Japan, Korea, Taiwan and USA; wood of *Accer saccharum* Marsh, *Castanea* Mill, and *Quercus* L., originating in North America countries; must be treated by kiln-drying (KD) to below 20% moisture content, expressed as a percentage of dry matter at the time of manufacture, achieved through an appropriate time-temperature schedule.

In the case of citrus originating from areas where is known the presence of Kanker citrus *Xanthomonas campestris* pv *citri* (Hasse), the fruit must be treated with sodium orthophenilphenate.

Exports

Exports are subject to the disinfestation requirements of the importing country. Exports of significant volume for treatment are grains (cereals and leguminous), fruit and vegetables.

In shipment of grain by sea, treatments are applied to the product as well as the ship. As a consequence of the Protocol of Montreal and the Directives of the International Maritime Organisation (IMO), MB has been substituted by generator granules of phosphamine, and disinfestations of ships is being made with contact pesticides in thermal fogging.

Main exports of our fruits and vegetables are forwarded to European countries where no quarantine treatments are required. However, Spanish citrus exports to different non-European countries (USA, Japan, Australia, New Zealand) are severely restricted unless certified free of fruit fly *Ceratitis capitata* (Wiedemann). Quarantine treatments must be carried out in order to certify the exports as free of fruit fly. Treatments applied are based on the application of cold treatment, which in our case the most used is the 16-day cold treatment with temperatures that that never exceed 2.2ºC. The treatment is made in-transit on ships or previously approved containers. The treatment is started on departure and the records are checked on arrival to ensure that the approved disinfestation temperature has not been exceeded.

CONCLUSIONS

Quarantine treatments using fumigation of MB have been substituted by other mechanical and physical methods for both imports and exports. In wood imports, fumigation with MB has been substituted by mechanical methods such as debarking or by physical methods such as heat treatments. Phosphine and fog systems of aqueous solutions of phosphorate products have substituted for MB in pre-shipment treatments for export grain (cereals and leguminous) and the equipment that carry these exports.

APPLICATION OF VACUUM TO SEALED FLEXIBLE CONTAINERS: A VIABLE ALTERNATIVE TO DISINFESTATION OF DURABLE COMMODITIES WITH METHYL BROMIDE

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ABSTRACT

This study forms part of a project aimed at eliminating the need for fumigation with methyl bromide (MB) to control stored product insects through the development of novel, vacuum-hermetic technology. First objective was to study the effects of low air pressures, temperature and exposure time on insect mortality in stored cocoa beans. A second was to study the potential of an innovative, transportable, sealed storage system as a practical tool for controlling insect pests at low air pressures. Two insects, both major pests of cacao beans in producer countries were used: *Ephestia cautella*, and *Tribolium castaneum*. The experiments conducted in the laboratory showed that the eggs were the most resistant stage to storage under a low air pressure of 55 ± 10 mm Hg at the two studied temperatures of 18°C and 30°C. Times needed to obtain 99% mortality of *T. castaneum* eggs at 18°C and 30°C were 96 and 53 hours respectively. For *E. cautella* eggs 99% mortality at 18°C and 30°C was obtained after 149 and 41 hours respectively. Two experiments were carried out in the field trial, each using 15 m^3 capacity plastic containers termed the "GrainPro Cocoon™" or "Volcani Cubes™", specially adapted to facilitate low pressure ("vacuum cube"). The pressure in the vacuum cube was established within the range of 23 to 75 mm Hg. In one cube, the low pressure was held for 3 days and in the second, for 7 days. In both cubes 100% mortality of all test insects was obtained.

Keywords: vacuum-hermetic technology, cacao, low pressure, *Ephestia cautella, Tribolium castaneum,* storage.

INTRODUCTION

Back and Cotton (1925) were the first to explore the possibility of using low pressures in post-harvest storage, followed by Bare (1948), and later by Calderon *et al.* (1966). However, to achieve the extremely low pressures necessary to obtain insect mortality, a prohibitively expensive investment in massively constructed vacuum chambers was required. The new terms of the Montreal Protocol, ending the use and production of methyl bromide (MB) in developed countries by the year 2005 and worldwide by 2015 (UNEP 1998), prompted us to re-examine the possibilities of using low pressures as a fumigation replacement to control stored-product insect infestations.

In a recent study by Navarro *et al.* (2001), a PVC-based, sealed, flexible storage system was developed to maintain low pressures. In this storage structure, low pressures of 25-30 mm Hg were achieved and maintained continuously for more than two months. These gas-tight, flexible structures were originally developed for long-term hermetic storage of grain, particularly for storage in developing countries, but they were also shown to be suitable for quarantine treatments using either modified atmospheres or the hermetic storage method. They are now in use on a commercial scale in several countries (Navarro *et al.* 1988, 1994; Navarro *et al.* 1990). The structures are made from plastic liners manufactured to specifications that provide a level of gas tightness that precludes significant loss of modified atmosphere or fumigant (Navarro *et al.* 1995). They are termed "Volcani Cubes™" or "GrainPro Cocoons™" (Navarro *et al.* 1999) and have potential for use in small-scale applications, particularly for high-value crops such as cocoa, coffee, and spices. In our field trial we used two of these structures, each of 15 m^3 capacity.

For our study, cacao beans were the chosen commodity and two insect species that are among the major pests of cacao beans: the tropical warehouse moth, *Ephestia cautella* (Walk.), and the red flour beetle, *Tribolium castaneum* (Herbst) were used for bioassay.

MATERIALS AND METHODS

Laboratory trials

Exposure of insects to low air pressure and temperature combinations: The sensitivities of the test insects were tested in chambers consisting of 3-liter desiccators filled with 1 kg cacao beans, and connected to a vacuum pump. The test chambers were held in an incubator kept either at 18°C or 30°C. Air pressures ranged between 45 mm Hg and 65 mm Hg (55 ± 10 mmHg) at a constant relative humidity of 55 ± 3%.

Test insects: Laboratory colonies of the moth *E. cautella* and the beetles *T. castaneum* were maintained in a rearing room at 28 ± 2°C and 70 ± 5% relative humidity.

Bioassay: Insects for the bioassay were chosen as follow: Eggs from each species were used within 0-2 days of oviposition. Larvae of *E. cautella* were 14-15 days old and *T. castaneum* larvae were 18-19 days old. Pupae of *E. cautella* were 1-2 days old and pupae of *T. castaneum* were 0-1 days old. *T. castaneum* adults were 30-31 days old and *E. cautella* adults were 1-2 days old. Each Bioassay contained two Perspex slides each holding 50-drilled "wells" that were used to place 100 eggs individually from each of the studied species, and were then covered with a cover glass to retain the eggs (Navarro and Gonen, 1970). In addition, 50 individuals (larvae, pupae or adults) from each of the studied species were placed in a small glass vial (4 ml), covered with paper or metal mesh and placed in each of the test chambers with the cacao beans.

Post fumigation procedures: Mortality of the test insects was determined as failure to reach the next developmental stage. Eggs of the two species were held in the rearing room for 10 days, after which the hatched larvae and un-hatched eggs were counted. Larvae and pupae were held for 2-3 weeks and observed three times each week. Survival of adult beetles was determined after 15 days, and of *E. cautella* 4 days after exposure, since their life expectancy is only about 4-6 days at 28ºC.

Statistical analysis: Probit analysis of log concentration against mortality of the treatments was carried out (Daum 1979). Where a significant probit line was not obtained, the shortest exposed time needed to achieve 100% was used.

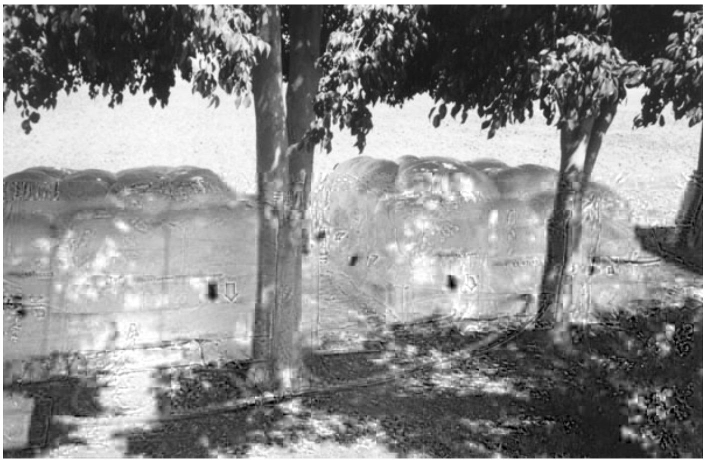
Field trial

Background: The field trial was conducted on March 2001 in Israel, at the Agricultural Research Organization (ARO) campus. Two vacuum cubes of 15 m^3 capacity, adapted to facilitate low pressure, were used. The pressure in the cubes was established using a rotary-vane, oil-lubricated vacuum pump (3 hp Becker model U 4.70, Germany) to within the range of 23 and 75 mm Hg for duration of 3 days in one cube and 7 days in the other. The commodity was cacao beans originating from the Ivory Coast (previously fumigated with methyl bromide). Each cube contained 100 jute bags each weighing 65-kg (total 13,000 kg per cube). Each cube was loaded manually and stacked with six layers of bags (Figure 1).

The vacuum cube system: In order to adapt the standard cubes to low pressure use, a quick-release hose and one-directional valve were incorporated. In addition, the system was connected to the pump using flexible 1.5" connecting tubes. The system was designed to be modular enabling the user to connect several cubes to the same vacuum pump, or to disconnect one of the cubes without changing the pressure in the other connected cubes.

Bioassay: Five sets of bioassay replicates were placed in each of the cubes, each set containing all life stages of *E. cautella* and *T. castaneum*. Four of the bioassay sets were located, one on each side of the four cube walls at mid-center height, and one at the top-center. The control bioassay was placed on the top, above the liner of the 7-day cube in an open plastic container filled with cacao beans. Temperatures at the top and at the four side faces of the cubes were recorded during the trials using data-loggers (HOBO Pro Series).

FIGURE 1: the two cubes (3 days exposures on the right and 7 day exposures on the left) connected together to the pump at the trial site under a pressure of 50 mm Hg.



RESULTS AND DISCUSSION

Laboratory trials

Cacao-beans are stored in burlap backs in the production countries of the tropics, and are subsequently shipped from the tropics to various ports in the Northern Temperate Zone from were they are transported to the processing plants. During the interim, the cacao beans are treated against insect infestation in both climatic zones and are exposed to different ambient conditions. In the tropics the commodity temperature fluctuates at around 30°C, while in the Northern Temperate Zone the commodity temperature can drop to below 20°C. It was therefore deemed necessary to study the influence of low pressures on insect mortality at both these temperature ranges. The exposure periods of low pressure required to control the life stages of *E. cautella,* as expressed in LT_{99} mortality values at 18°C and 30°C are presented in Table 1 and for *T. castaneum* in Table 2.

Table 1: The effect of low pressure (55 ± 10 mm Hg) on mortality as expressed in LT99 (hours to obtain 99% mortality) values for the developmental stages of *Ephestia cautella* at 18°C and 30°C

Developmental Stage	LT_{99}[1] at 30°C (range)	LT_{99}[1] at 18°C (range)
Egg	40.7 (36.16 - 50.34)	148.8 (172.22 - 133.23)
Larva	< 28	43.6 (76.63 - 32.33)
Pupa	< 8	26.2 (139.87 - 17.48)
Adult	< 10	76.7 (180.35 - 54.88)

[1] Numbers in brackets are the 95% confidence limits.

TABLE 2: The effect of low pressure (55 ± 10 mmHg) on mortality as expressed in LT99 (hours to obtain 99% mortality) values for the developmental stages of *Tribolium castaneum* at 18°C and 30°C

Developmental Stage	LT_{99}[1] at 30°C (range)	LT_{99}[1] at 18°C (range)
Egg	53.0 (46.51 - 63.98)	96.3 (139.8 - 73.29)
Larva	< 28	36.8 (58.08 - 28.69)
Pupa	< 38	71.8 (102.70 - 58.53)
Adult	< 28	29.9 (151.67 - 26.62)

[1] Numbers in brackets are the 95% confidence limits.

The results show that for both species, the egg was the most resistant stage at both 18°C and 30°C. For *E. cautella* the time needed to obtain 99% egg mortality at 18°C was 149 hours and at 30°C it was 41 hours. The times needed to obtain 99% mortality of *T. castaneum* eggs were 96 hours and 53 hours at 18°C and 30°C, respectively. The influence of temperature on mortality was more dramatic for *E. cautella,* with a one third reduction in the time needed for control of all life stages at 30ºC. At 18°C, *E. cautella* showed a higher resistance to low pressure then *T. castaneum* while at 30°C this tendency was reversed and *T. castaneum* was more resistant to the treatment at all life stages.

Field trial

Pressure within the two test cubes was regulated at of 23-75 mm Hg for the two time durations. Subsequent bioassays revealed complete mortality within three days of exposure for all life stages of the two insect pest species, *E. cautella* and *T. castaneum.*

The pump required 55 minutes to reduce the pressure in the two cubes to 23mm Hg. The suspension time between pumping was 10 min at the first day of the trial. For the three-day exposure cube, temperature at the top of the cube was 28.0 ± 0.5^{0}C and the relative humidity stabilized at 65%. At the northern cube-wall face the temperature was 27.9 ± 1^{0}C and the relative humidity stabilized at 69.5%. For the seven-day exposure cube, the temperature at the top was 27.9 ± 0.5^{0}C and the relative humidity stabilized at 69.9 ± 0.5% at the top and the northern cube-wall face of the cube.

In conclusion, the low-pressure/vacuum treatment was successful in providing total mortality of the insects pests and in protecting the commodity from re-infestation. Furthermore the cube provided protection for the cocoa beans from loss or increase in moisture during storage. These results indicate that effective control can be obtained in less than three days.

ACKNOWLEDGMENTS

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CASE STUDY: SULFURYL FLUORIDE FOR DISINFESTATION OF TIMBER AND STRUCTURES

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ABSTRACT

The fumigant sulfuryl fluoride, SO_2F_2 (SF), is currently used to control wood-destroying and household insect pests and is recognised as an alternative to methyl bromide (MB) for the control of stored product insects. SF, as the product Vikane[7] Gas Fumigant, is used for the disinfestation of timber and non-food structures and is licensed or registered for use in a number of countries including Germany, Sweden and the USA. SF is effective on all life stages of insect pest and contains no chlorine or bromine and therefore does not contribute to stratospheric ozone depletion. Dow AgroSciences enforces a strict product stewardship policy to augment the training and certification required by government authorities. SF, as the product ProFume[6] Gas Fumigant, is under development as a post-harvest fumigant on food products with registrations expected in the USA in 2002/3 and in Europe in 2003/4.

Keywords: Sulfuryl fluoride, Vikane, ProFume, fumigation, stored products

INTRODUCTION

The fumigant sulfuryl fluoride, SO_2F_2 (SF), is currently used to control wood-destroying and household insect pests. It has been recognised as an alternative to methyl bromide (MB) for the control of stored product insects (Bell, 2000; USDA, 2000). SF, as the product Vikane[*] Gas Fumigant, is used for the disinfestation of timber and non-food structures and is licensed or registered for use in a number of countries including Germany, Sweden and the USA. In the USA it has been used since 1961 primarily for drywood termite control. Over one million buildings have been fumigated including homes and museums. In Europe, the main use is in Germany to eliminate wood destroying beetles e.g. *Anobium punctatum* and *Ptilinus pectinicornis* from structures. In Sweden, SF is used in shipping containers and for the disinfestation of homes and wooden artefacts. SF, as the product ProFume[8] Gas Fumigant, is under development as a post-harvest fumigant on food products with registrations expected in the USA in 2002/3 and in Europe in 2003/4.

FORMULATION AND PROPERTIES

SF is a non-flammable, colourless, and essentially odourless gas. It is an inorganic compound and is essentially non-reactive with structural materials. SF has a low boiling point (-55^{o}C) and a high vapour pressure (13,442 mm Hg at 25^{o}C) and readily vaporises under normal fumigation conditions enabling rapid dispersion following introduction. The gas rapidly penetrates porous materials like wood and has low sorption on fumigated materials. SF also rapidly aerates from materials and commodities and does not react with materials to form unpleasant odours. Although of low reactivity as a gas, SF at temperatures exceeding 400^{o}C will beak down and react with water to form hydrogen fluoride which can etch metals, glass or other polished surfaces. Therefore, prior to fumigation all open flames should be extinguished and glowing heat filaments disconnected.

ENVIRONMENTAL FATE

SF is fully oxidised and does not interact with or contribute to local ozone formation (Bailey 1992; Chambers & Millard 1995). It contains no chlorine or bromine and does not contribute to stratospheric ozone depletion (Thoms & Scheffrahn 1994). The relatively small amounts of SF released are calculated to have virtually no impact on global atmosphere and the environment. SF is broken down mainly through hydrolysis to release fluoride and fluorosulphate ions (Bailey, 1992).

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[7] Trademark of Dow AgroSciences. ProFume is not currrently available for sale. Registration is pending.

[8] Trademark of Dow AgroSciences. ProFume is not currrently available for sale. Registration is pending.

EFFECTIVENESS

Mode of action

Studies have been completed which indicate that SF has several biochemical effects on target insect pest species. Mortality is achieved by disruption of the glycolysis cycle depriving the insect of metabolic energy (Meikle *et al*. 1963). SF is effective on all life stages of insect pests. Larvae, pupae and adult insects are highly susceptible to SF while eggs and diapausing life stages require higher doses. Research has indicated that the lower activity on eggs is primarily due to reduced penetration through the eggshell. Effective dosages for all insect life stages can be obtained by varying concentration and exposure time.

Studies on stored insect pests in structures

To validate laboratory chamber fumigations with SF on stored product insects (SPI) fifteen trials were completed in empty food milling/processing structures in Germany, Italy, UK and the USA during 1997 – 2001. These studies confirmed excellent efficacy on all life stages of SPIs' including *Tribolium castaneum*, *T. confusum*, *Plodia interpunctella* and *Ephestia kuehniella*.

Studies on timber pests

Thoms and Scheffrahn (1994) explained the technical foundation of SF dosages for insect pests as well as describe the tools and techniques for properly using this fumigant to control structural insect pests. Binker (1993) described a customised Vikane fumigation process, including introduction, exposure, and aeration, that Binker Materialshutz has used for several years to control wood-infesting pests in churches in Germany. Scheffrahn *et al.* (1992) reported on the penetration of SF into wood, which is more rapid than for MB when the wood is not hydrated. Soma *et al.* (2001) demonstrated that SF sorption into wood is substantially less than MB sorption. The use of SF as an alternative to MB for control of structural (non-food) insect pests is summarised in a case study published by the Environmental Protection Agency of the United States (1996). Derrick *et al.* (1990) provide a thorough review of SF use as fumigant to control pests of museums and historical structures and artefacts.

STEWARDSHIP

SF is for use by professional, licensed fumigators. Dow AgroSciences enforces a strict product stewardship policy to augment the training and certification required by government authorities. In common with other fumigants, SF has hazards that require full understanding and correct execution of application and safety measures to ensure effective pest control with minimal risk to fumigators and the public.

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ALTERNATIVES TO METHYL BROMIDE FOR TREATMENT OF GRAIN AND SEEDS

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ABSTRACT

A review of alternative control methods for grain and seeds shows that no single alternative is available to replace methyl bromide (MB). Phosphine, and a limited number of other pesticides, are currently available. However, at present there is concern with regard to the effectiveness and toxicity of these products. The future approach will be an integrated pest management system that considers all chemical and nonchemical (biological, physical, hygiene) methods adapted to each specific situation. Among chemicals, new classes of insecticides that are more specific and environmentally acceptable, botanical fumigants and repellents, and carbon dioxide, seem to be the best alternatives.

Keywords: Grain, seeds, stored product pests, integrated pest management, fumigation.

INTRODUCTION

Since ancient times cereals and seeds have been stored in different types of facilities. The presence of pests in stored products is documented from the time of the early Egyptian Dynasties. Although losses in stored grain or seeds due to pests are difficult to calculate, estimates of losses in developing countries are always about 20-30% (Gwinner *et al.* 1996). In developed countries, losses in quantity are not as important as losses in quality and the main concern is damage to the product which can be seen by customers, and pesticide residues. Standards in food safety increasingly demand the absence of insects, mites, microorganisms, mycotoxins, allergens and other contaminants.

Up to now, pest control has depended almost entirely on pesticides and the fumigant methyl bromide (MB) is one of the most important among them. Replacements for MB are urgently needed since it is scheduled to be phased out for general use worldwide due to its depleting effects on the ozone layer (UNEP 2001). Fumigations with phosphine (magnesium/aluminium phosphide preparations) and a limited number of synthetic organic insecticides are commercially available. All these pesticides are also highly toxic and harmful to the environment. International food safety legislation tends to prohibit or restrict pesticides suspected of remaining in food as toxic residues.

Phosphine appears to be effective for the control of several pest species. However, it requires longer treatment periods than those used with MB. In recent years, there has been some concern over the misuse of phosphine which has resulted in resistance in several pest species. It is highly important to establish and respect the most appropriate concentrations and exposure times in each particular situation. A cylinder gas formulation of phosphine and specific application technologies have been developed in Australia (Banks 1994). Advantages of these recent technical developments are shorter exposures, ease of application and reduced risk of uncontrolled leakage.

Minor fumigants have been used for many years such as chloropicrin, sulfuryl fluoride and cyanhydric acid registered in some European countries for structural treatments. A number of other potential fumigants have been studied for decades: carbonyl sulfide, carbon disulfide, ethyl formate and others (Banks 1994). However, their widespread use has been impeded by concerns over residues, environmental safety and, in general, their toxicology. Therefore, currently there is no single alternative to substitute for MB and possible restrictions on the use of phosphine.

NEW PEST CONTROL STRATEGIES

Pests that affect grain and seeds have a cosmopolitan distribution. In our area in Spain, a total of twenty-two species of arthropods were found in six types of grain cereals and seeds (Riudavets *et al.* 2001). Coleoptera and Lepidoptera were the main groups of arthropods collected, but psocids, wasps, thrips and mites were also present. Usually a high diversity of organisms is present at the same time in a storage facility. Knowledge of the interactions between them and the stored material is crucial to understanding the whole ecosystem. A pest management strategy must address the complex of organisms present and also take into account the management of abiotic factors such as temperature and relative humidity that affect their development.

An advanced approach to pest control, as an alternative to the regular use of pesticides, is known as integrated pest management (IPM) or more broadly, integrated commodity management. Chemical and nonchemical control methods are selected that complement each other thereby minimising the negative effects to human health and the environment in order to achieve economic protection from pest damage. Management strategies, hygiene, building design, inspection, biological and physical control methods are all useful to reduce pest populations, and whenever possible the use of pesticides is limited and much more effective.

There are many examples in the literature where successful pest control is economically achieved without the use of pesticides (Zuxun *et al.* 1999). Among physical control methods, meshes are set up to restrict the movement of pests, inert dusts are applied to protect the boundary layers of grain storage structures and mechanical devices are used to destroy insect eggs during the milling process.

Several insect parasitoids and predators are known to control stored product pests. However, very few natural enemies are commercially available in stored product protection. Microbial biocontrol agents based on *Bacillus thuringiensis*, fungus or viruses are already commercially available. However, their use in grain or seed storage facilities is not yet registered. Future research is needed on their practical application for control of stored product pests.

Chemical alternatives to classical pesticides include growth regulators (juvenile hormone mimics, ecdysone agonists and inhibitors of chitin synthesis), biofumigants (phytochemical compounds from plant products investigated as fumigants or repellents of pests) and atmospheric gases.

Among potential new fumigants for controlling stored product pests, carbon dioxide seems to be one of the best alternatives. Its advantages include no residues, existing registration, use for the food industry without a safety interval following treatment, and it is recyclable. The application of carbon dioxide under pressure, and preservation by modified atmospheres with high-carbon dioxide concentration, are two control methods useful for the agro-food industry. The effectiveness of both alternative technologies has been determined for the control of the main insects and mites found in grain or seeds (Table 1). Pressure treatments require short time periods and are highly effective. Modified atmospheres are easily applied to the packaging of manufactured products or when raw materials are stored. Furthermore, effective treatments require long periods and gastight systems.

Table 1: Conditions established for the control of main insect and mite pests of stored products using modified atmospheres and CO_2 under pressure.

	MODIFIED ATMOSPHERES	
CO_2 concentration	O_2 concentration	Exposure times
50% - 90%	<5%	4 days – 20 days
	CO_2 under PRESSURE	
Pressure	Exposure times	Decompression
15 atm – 20 atm	15 minutes – 120 minutes	0.5 minutes – 10 minutes

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MICROWAVE ENERGY AS A VIABLE ALTERNATIVE TO METHYL BROMIDE AND OTHER PESTICIDES FOR RICE DISINFECTION INDUSTRIAL PROCESSES

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ABSTRACT

Methyl Bromide (MB) is the pesticide commonly used for both food products and soil disinfecting processes. The main drawback for MB use is its contribution to the depletion of the ozone layer and it is a tremendous hazard for human health. Rice must be properly disinfected after harvesting prior to commercialisation. Since MB use will be forbidden from 2005 onwards in developed countries, it is necessary to search for a viable and equally effective alternative. The use of microwave energy in domestic applications has now become commonplace and its viability for many other industrial heating, thawing, drying and disinfecting processes has already been demonstrated. The aim of this paper is to describe the use of a pre-industrial microwave applicator for rice disinfestation. The applicator is the result of a 4-year R&D project that involved both academia and industry. The patent-protected modular system allows for continuous treatment at a user-customised speed for economic viability.

INTRODUCTION

An effective way of killing insects of all kinds is to elevate their body temperature above a certain lethal value using microwave energy. Previous studies have shown that the adequate temperature range required to achieve a 100% insect mortality in a commodity lies between 45 and 60°C [1]. Microwave heating is closely linked to the dielectric properties of the material being heated. Hence, the success or failure of disinfecting treatments using microwaves strongly depends on precise knowledge of the material to insect ratio of the dielectric properties and the dielectric properties themselves. For rice disinfecting, it becomes very important to achieve selective heating, namely, to induce a lethal temperature in the insects while not modifying neither the appearance nor the nutritive value of the commodity. The parameter upon which the behaviour of a material respect to microwave heating is based is the complex dielectric permittivity,

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1)$$

where ε' and ε'' are the dielectric constant and loss factor, respectively.

The dielectric properties at 2.45 GHz of rice weevils and four different varieties of rice where studied. Long rice grain (Puntal), medium size pearled rice grain (Senia), medium size crystalline rice grain (Thainato) and short rounded rice grain (Bomba) were selected due to their large consumption in Spain. Measurements were performed based upon reflection measurements of partially filled WR-340 waveguides and perturbational formulae taken with the use of a HP-8720-B Network Analyser. The ratio between the rice and the weevils loss factor was found high enough to ensure process viability and selective microwave heating. Providing a way of avoiding insect migration to cold areas had to be incorporated into the design.

APPLICATOR DESIGN AND SIMULATION

The tool employed for the applicator design has been the 3D electromagnetic suite MAFIA (Maxwell Finite Integration Algorithm), where important trade-offs between accuracy and computational requirements were found. Practical design of the multimode cylindrical applicator is based upon three main factors: heating uniformity, mutual coupling and mode distribution.

Heating uniformity is main problem for multimode ovens. A way to improve uniformity and thus heating effectiveness is to employ several low-power feeder waveguides rather than one high-power input. This also helps lower maintenance costs since a high-power magnetron source usually costs much more than a few low-power magnetron sources [2] (Figure 1). Similarly, a cylindrical cavity was used as this is often appropriate for microwave applications due to its simplicity and because it improves the heating efficiency [3]. Strong mutual coupling, on the other hand, may lead to undesired energy within a magnetron head cavity, and hence lead to the destruction of the head. In order to avoid strong mutual coupling, the feeding waveguides must have different orientations when feeding the main cavity. Finally, an appropriate mode distribution depends on cavity size and shape, dielectric properties and position within the applicator.

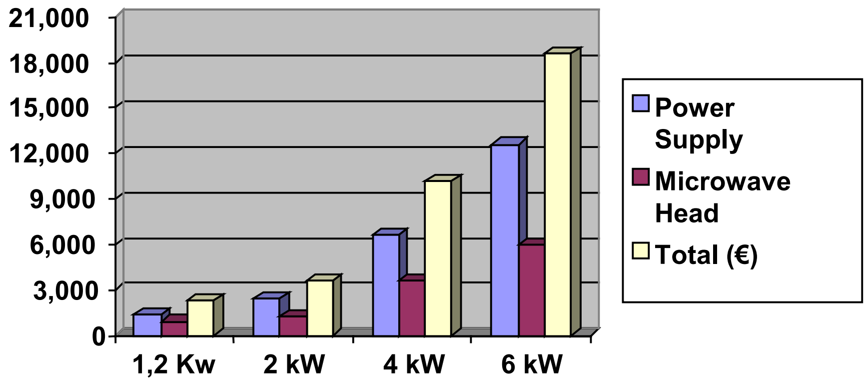


Figure 1: Comparison of cost for low- and high-power microwave energy sources.

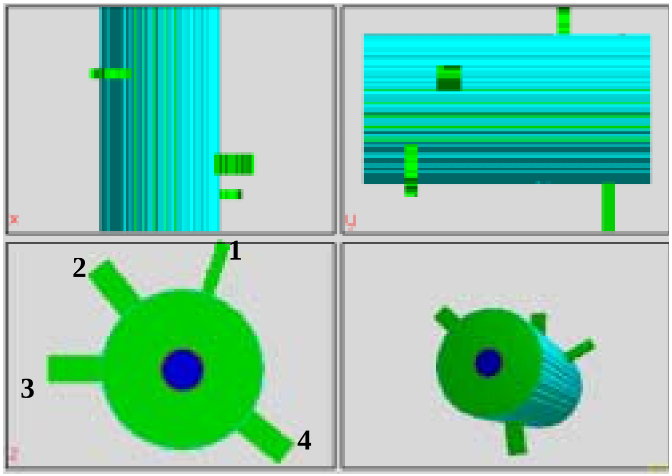
Taking into account that the system has to provide an economically viable disinfecting regime, with maximum heat transfer and uniformity within the cavity, the applicator was designed at the Technical Universities of Carthagene and Valencia, and built at Rymsa-Cixmo S.A. From all different simulations, the combination that best conform to specifications using eight feeder waveguides (only four are depicted) is shown in Figure 2 where a modular building block that can easily be combined to form parallel or series arrangements is illustrated. The electromagnetic performance of the building block in terms of both VSWR and mutual coupling is shown in Table 1.

Table 1: The electromagnetic performance of the building block in terms of both VSWR and mutual coupling.

VSWR			
S_{11}	**S_{22}**	**S_{33}**	**S_{44}**
2.45	2.75	2.14	1.76

Mutual Coupling (dB)					
S_{21}	**S_{31}**	**S_{41}**	**S_{32}**	**S_{42}**	**S_{43}**
-31.5	-22.7	-32.78	-23.7	-22.7	-15.5

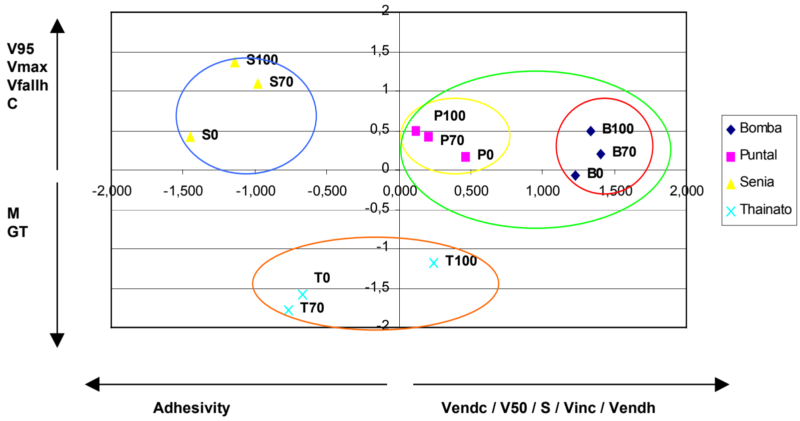
Figure 2: Building block for the rice disinfecting applicator.



It has also been demonstrated that the minimum energy requirements for a 100% mortality in rice disinfecting processes using the applicator type described in this paper is around 100 J/g [4], and thus testing procedures were prepared for 70 J/g (under treatment) and the correct 100 J/g at a laboratory scaled down applicator prototype. Several quality criteria parameters for rice were tested both before and after treatment, and compared to untreated samples. Moisture content (ISO712), water uptake, colour, response to heating, cooking and cooling (AACC-061), gelatinisation consistency, temperature and time of rice starch (ISO 14864:1998E), amylose content, decomposition of rice kernel, optimum cooking time and texture (TA XT2i) were tested, among some others.

Due to limited publication space, only the results of the statistical analyses that were performed for each variety with all its different test results will be depicted here. In the multi-variable analyses, significant correlation values from below –0,7 and above 0,7 were accounted for. bIn the statistical analyses, two factors accounted for 86,64% of the standard deviation, while the rest was attributed to a third factor. The results for factors 1 and 2 are depicted in Figure 3. Figure 3 shows that more differences can be found between varieties than between samples treated and untreated with weevil mortality-effective microwave energy within each variety. Bomba and Puntal varieties were grouped closer to factor 2, wherein consistency, maximum viscosity, 95°C viscosity and viscosity attributed were considered. Senia variety was grouped to the adhesivity attribute of factor 1, like Thainato variety, although this last one was more disperse and approached factor 2.

Figure 3: Results of statistical analyses.



V, Viscosity; V50, viscosity at 50°C (cooling); V95, viscosity at 95°C (heating); Vmax, maximum viscosity; Vendh, final viscosity after heating; Vfallh, viscosity fall after heating (Vmax-Vendh); Vendc, final viscosity after cooling; Vinc, viscosity increase after cooling (V50-Vendc); S, setback (Vmax-V50); C, consistency; M, moisture content; GT, gel temperature.

CONSTRUCTION

With the scaled-down data and the modular approach, a full-size pre-industrial applicator able to treat 250 kg per hour was designed and built. The centre of the cavity consisted of a hollow doped-PTFE tube to prevent rice from spilling over the whole applicator and keep it within the concentrated and uniform high field distribution. The radius of this hollow doped-PTFE tube had been designed considering both regime and penetration constraints. The final applicator is illustrated in Figure 4, and with a total height of 3.8 meters and width of 1.1 metres, it contained eight 850 W microwave sources, requiring an electrical supply of 8.5 kW/h for proper operation. Figure 4 at the end of the paper shows the industrial user-customised applicator.

CONCLUSIONS

A complete pre-indsutrial applicator for rice disinfecting eliminating Methyl Bromide has been designed and manufactured. The use of microwave energy for industrial rice disinfecting processes slightly modifies rice quality parameters while completely eliminating the use of Methyl Bromide. Found changes depend upon variety, although these are so petty that no commercial drawbacks are foreseeing qualitywise. Likewise, standard deviation in quality parameters is higher between varieties than between treated and untreated samples within varieties. More research is been carried out to find out whether standard deviation in quality parameters can also be compared to standard deviation within variety batches.

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Figure 4: Industrial user-customised applicator.

HERMETIC STORAGE OF GRAIN IN CYPRUS

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ABSTRACT

In Cyprus, five different structures for Hermetic Storage of grain collectively have an 85,000 tonne capacity which represents approximately 30% of the total storage capacity of the country. The "Bunkers and Platforms under PVC" liners, and the "Airtight Concrete Bins", were the more important of these hermetic structures. Bunkers and Platforms under PVC liner were low cost grain storage structures (approximately US$8,5/tonne). The labour needed for filling and emptying one Bunker of 12,000 tons capacity required approximately 650-850 man-hours for each operation. The cost for filling, emptying, grain protecting, providing liner materials and maintenance of one Bunker of 12,000 tons was approximately US$1.83/tonne. Loading and out-loading machines of 300 tonnes/h were used. The introduction of hermetic Bunkers in the grain storage system provided the possibility for a) receiving the local production for safe storage in a short time b) taking advance of low prices in the international market c) increasing the grain storage capacity and grain stock using minimal capital d) successful protection of grain against insects, rodent contamination, bird attacts and losses caused by rain e) reduction in the use of insecticides including methyl bromide. The combination of hermetic storage with grain aeration, advanced fumigation technologies like Siroflo and good management will be essential for profitable and ecologically-friendly grain handling.

Keywords: grain, storage, hermetic, airtight, bunkers, silo, plastics, alternatives, methyl bromide

INTRODUCTION

In many ancient civilizations people used to store grain in different structures like clay jars, mud-plastered underground pits, above-ground oven-shaped mud-plastered domes and other structures. In some of them, a thick layer of earth and well-sealed openings provided a certain degree of airtightness. The combination of hermetic conditions with low grain moisture could protect the grain for a long time. Similar structures were used in many countries even some decade's years ago for grain storage. For example, in Cyprus in some villages until the first decades of 20th century, wheat was stored in oven-shaped mud-plastered structures with both openings well-sealed and in mud-plastered underground cavities called "Gouffes".

Modern hermetic storage is based on the same principal, but new materials and technologies are used. Cement, polymers like PVC and polyethylene liners, iron, fiberglass and sealants like silicone are some of the new materials used in building structures for hermetic storage of grain. A great variety of these hermetic structures can be seen in many countries: underground pits, bunkers and platforms covered by plastic liners, mobile plastic bag-silos, metal bins and sheds, concrete silos with plastered their inner walls with sealing materials, large domes built by using cement, plastic and fiberglass. The capacity of some of these hermetic structures is 50-100 thousand tonnes each.

HERMETIC STORAGE OF GRAIN IN CYPRUS

In Cyprus, five different structures for hermetic storage of grain are used of a total 85 thousand tons capacity, representing approx. 30% of the total storage capacity of the country. The so-called "Cyprus Ctessifon underground pits" were the first hermetic stores built in Cyprus in 1956. Their capacity is 1,200 tons each and, at that time, they served as an experiment for building storage silos in other countries based on the idea of airtightness.

In 1987, four hermetic Mobile Silos of 1,000 tons capacity each and two hermetic Platforms of 7,000 tons total capacity were erected in Cyprus, in co-operation with Volcany Center, Israel. In Mobile Silos, consisting of an UV PVC bag in an iron-made round frame, wheat and barley were stored up to one year without using insecticides. The O_2 concentration could be reduced by up to 5% and the CO_2 by up to 14%. An aeration system was used to minimize the condensation on the top.

The two hermetic Platforms are 25m wide and 75m long, with a concrete base and 1.2m height concrete walls. The floor is covered with a 250 mm polyethylene. Grain is covered with an UV PVC liner of 720 mm thickness. Liner is non-permeable to water, O_2, CO_2 and PH_3. Barley of max. 11.5% moisture is stored in these Platforms up to 3 years without using any insecticides. Grain is successfully protected against insects, rodent and bird's attacks and contamination. If Platforms are well sealed, the O_2 concentration is reduced up to 3-6% and the $C0_2$ is increased up to 12%. At the end of storage no samples containing live insects are recorded. The germination of grain remains above 88% even after 3 years of hermetic storage. In addition to the low structural cost and ecological advantages, storage losses can be compared favorably with weight losses in conventional structures. Total storage losses represent after 1 year storage approx. 0.3%, after 2 years approx. 0.5% and after 3 years of storage approx. 0.9%. Total of fixed cost (including the building of Platforms, a Stacker of 300tons/hour and liners) and current cost for 1 year storage of 4,000 tons barley are approximately US$4.50/tonne.

The fourth type of hermetic structure used in Cyprus is a complex of 3 airtight Concrete Silos of 2,500 tons capacity each. These bins are used not for long-term storage, but for fumigation of grain using broken (crushed) phosphine tablets followed by aeration. This has the following advantages: a) successful fumigation using very low Phosphine doses b) no need for liquid insecticides or methyl bromide (MB) c) no insecticide residues in grain.

The fifth type of hermetic structure used in Cyprus is a system of 6 hermetic Bunkers of total 70 thousand tons capacity. This technology was introduced in Cyprus in 2001 in co-operation with SACBH, Australia. Each Bunker is 130m long, 30m wide and approx. 10m height and set on an east-west axis (west is the main direction of wind). Bunker walls are formed by joint one to another 3m long and 1,3m height corrugated steel walls with fabricated "A" metal frame support. The walls are secured to the ground by pegs through the frames. The Bunker base is of compacted crushed rock of 200mm thickness. Before filling the Bunker with grain, the floor is covered with a polyethylene liner of 200µ thickness. Walls are covered by polyethylene coated fabric which extends from the ground and interlocks with the top trap creating a gas and water sealed structure. The grain is loaded using a Over Drive Hopper and a Stacker of 300 tonnes/hour capacity. Grain is covered with a 520µ thickness reinforced PVC of 3-years service life. The liner is not permeable to water, O_2, $C0_2$ and PH_3. This cover successfully stood up during last December to gale of 20-25 m/sec at 2 and 10 m height and heavy rainfall of 70mm in one day. The sheets have an ice-blue colour, friendly to the environment.

Four 18.5 kW fans are used for grain aeration, controlled by a computer operating on the difference between the wet-bulb temperatures of grain and ambient air. Aeration of Bunkers is an innovation and it is expected to minimize condensation at the apex of Bunker and enable the storage of grain of higher than 12.5% initial moisture content. Bunker is an excellent structure for grain fumigation with Phosphine. In fumigations of Barley using a dose of 0.5 g ai/tonne, the PH_3 concentration was maintained for 15 days above 60 ppm. Good sealing of the Bunker is very important. After the end of fumigation, the grain is aerated to remove Phosphine residues and to reduce the grain temperature.

The total expenditures for building 6 Bunkers of total capacity 70 thousand tonnes (including 17ha of land of US$0.5 million, building and roads) was US$1,777,000 or US$25/tonne. The cost for the Bunkers' machinery, apparatus, walls, sheets, aeration system and data loggers was US$577,000 or US$8.2/tonne (Table 1).

Table 1: Per item cost of building six hermetic Bunkers of 70,000 tonnes capacity in Cyprus

Type of Expenditure	US Dollars	Life in years
Bunkers walls, supporting frames, corrugated sheets etc	93,000	20
Drive Over Hopper, Stacker	178,000	15
Aeration fans and Ducts, Aeration controller	52,000	10-20
Data loggers, Software	13,000	5
Top-cover PVC sheets	79,000	3
Floor-cover polyethylene sheets	5,000	1

Type of Expenditure	US Dollars	Life in years
Packing, Insurance, Erection, Testing, Design, Training etc.	154,000	-
TOTAL	**577,000**	

For filling and emptying one Bunker of 12,000 tonnes, 8 persons were needed (one grain inspector, one person for weighing, two techniciants, 4 workers). The labour for filling one Bunker of 12000 tonnes was approximately 650 manhours during summer and 850 man-hours in winter. A little less labour is needed for emptying. The cost for filling, emptying, 1-year grain protection, liners, fuel and maintainance of one Bunker containing of 12,000 tonnes of grain as approximately US$20,000 or US$1.83/tonne (Table 2).

Table 2: Per item cost of filling, emptying, 1-year grain protection, liners and maintainance of one Bunker containing 12,000 tons of grain.

Type of Expenditure	US Dollars	US$ per tonne
Filling and emptying the Bunker	13,500	1.13
Fumigation, aeration, rodent control etc.	1,500	0.13
PVC sheet for covering the grain	4,500	0.36
Polyethylene for covering the floor	1,000	0.08
Maintenance of Bunker and machinery, fuel, oil etc.	1,500	0.13
TOTAL	22,000	1.83

CONCLUSIONS

1. Hermetic Bunkers and Platforms under PVC liner is a low cost grain storage facility (about US$8.5/tonne) and a fast way to increase storage capacity of a country or a company. This provides the possibility for a) securing the local production in a short time b) taking advance of low prices in the international grain market, that is important for importing countries c) increasing the grain stock d) successful protection of grain quality e) reduction of insecticides use, no need for liquid insecticides and MB.
2. The expenditure for building hermetic Bunkers and Platforms was about 7.15 and 25 times lower in comparison to the expenditure for building conventional flat shed, metal and concrete silos of the same capacity, respectively.
3. The labour needed to fill one Hermetic Bunker of 12,000 tonnes capacity was about 650-850 man-hours and for emptying a little less. The cost for filling, emptying, maintainance including liners and 1-year grain protection of one Bunker of 12,000 tonnes was approximately US$20,000 or US$1.83/tonne.
4. In hermetic Platforms, the reduction of O_2 up to 3-5% and the increase of CO_2 up to 10-12% may suppress the insect development without using insecticides. In hermetic Bunkers and Bins a successful fumigation using reduced doses of phosphine can be carried out, followed by aeration to remove phosphine residues.
5. The major problem in using hermetic Bunkers and Platforms for grain storage is the increased need of manual labour, the break in work during rainy days and the moisture migration towards the peak. The storage of grain with low moisture content (below 12.5%), the new possibility for aeration of grain in Bunkers, and the flattening of the structural configuration at the apex, reduce the mould losses at the peak.
6. The hermetic method of storage provides successful protection of grain against insects, rodent contamination, bird attack and losses caused by rain, reduces the need for using liquid insecticides or MB and it has ecological advantages.

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Photo 1: A group of Bunkers of total 70 thousand tons capacity for hermetic storage of grain in Cyprus. An aeration system, controlled by a computer using data from a meteorological station, is installed in two of these Bunkers, to control the grain temperature and moisture migration, to increase the acceptable initial grain moisture content and to remove the phosphine residues after fumigation.

Photo 2: The historic "Cyprus Ctessifon semi-underground pits" built in 1956 and served as an international model for studying the possibility of using hermetic structures for grain storage.

TOMATO PRODUCTION IN SPAIN WITHOUT METHYL BROMIDE

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SUMMARY

Tomato, a basic product in Spanish horticulture, occupies 14% of the horticultural surface cultivated and contributes to 23% of the value of the sector's production. Spanish tomatoes satisfy the interior demand and have a strong export demand. About 25% of the fresh production and 50% of the canned fruit are exported. Crop management systems for tomato production in Spain require, as the principal alternatives to methyl bromide (MB), hybrid varieties with resistance to pathogens and soil fumigation with other conventional fumigants. New "long life" varieties that possess the *Mi* gene have overcome the problem of susceptibility to the nematode genus *Meloidogyne*. The "Mediterranean system" for producing tomatoes for fresh consumption is much more effective in controlling diseases and yields better quality fruit than the "Dutch system" which is based primarily on cultivation using substrates.

Keywords: fungi, nematodes, soilborne, fumigants, crop management, methyl bromide, alternatives

INTRODUCTION

In order to understand the reasons why tomato crops in Spain do not generally use methyl bromide (MB) for soil disinfestation, a preliminary analysis is necessary of cultural techniques and of the crop innovations that have been introduced in the last thirty years. This analysis should be done for crops produced for fresh consumption as well as for crops for processing (e.g., paste, sauce) and canning. Both subsectors are defined as different activities because of their production techniques as well as their geographic distribution.

Tomato production for canning is an extensive, seasonal crop confined to Mediterranean countries, whereas tomatoes destined for fresh consumption have an intensive production and extend throughout the European Community.

Both subsectors of tomato crops have followed different technological paths. Nevertheless, in both cases, technical change has sought an increase in output per surface unit and crop adaptation to less favorable climatic conditions. Developments have included out-of-season and greenhouse crop production. This change has been accompanied by new criteria in consumer conduct, which is a concern for a healthy diet. Among Europeans, disquiet exists over the degree of safety in foods, an uneasiness which carries implicit criticism of intensive production methods and their contaminating effects (Aldanondo Ochoa 1995). Regulations on the maximum residue limits for horticultural products reflects well this concern, a concern that reaches as far as to the deterioration of our surroundings, even though they may be as distant as the stratospheric ozone layer. The growing interest of the large distribution chains to establish commercial trademarks for more natural products (organic, ecological, etc.), is a phenomenon that is influencing the tomato-producing areas of Spain, starting with the advantage of scarce or nil use of MB in its crops (Bello & Tello 1997).

PRODUCTION TECHNIQUES IN THE PAST THIRTY YEARS

In the three years from 1990-1992, the EU produced a total of 13,118,000 tonnes of tomato of which 22% was produced by Spain (Aldanondo Ochoa, 1995). This analysis of the changes in production techniques will be centered on tomato for fresh consumption, since the cultivation of tomato for canning in Spain does not normally use MB.

There are two models for tomato production in the EU: Holland, Belgium, the United Kingdom, Denmark and Germany primarily use the "Dutch system" in which tomatoes are cultivated in greenhouses on substrates (principally rockwool) with a central hot water heating system, and computerized control of environmental constants and of the watering system. Generalization of soilless cultivation — partly mandated by the strict prohibition of MB — varietal improvements, innovations in the design of greenhouses and the perfection of agricultural practices, has permitted output to reach spectacular levels (400 t/ha, triple the production of Spanish greenhouses). This system is especially expensive in energy (e.g. heat, fertilizers) and in production per unit (from 20-30% above that of Spain's). Also, the system is particularly contaminating. It is calculated that substrate crops require two to three times more fertilizer than field crops. The degradation problem surrounding agricultural areas in Holland, where production is particularly intensive, has instigated government plans to minimize them.

Among other modifications to improve this system of production are savings in energy consumption, a decrease in the use of fertilizers and pesticides and, particularly, a closed circuit for recycling the water used for irrigation. In this way, these growers aim to halt one of the major sources of contamination: the filtration of pesticides and fertilizers into the waterbeds. The advantages of the system are as certain as its remarkable rise in production costs (Aldanondo Ochoa 1995).

The "Dutch system" has been considered the archetype of efficiency. Nevertheless, the growing preoccupation of consumers about the environment and the safety of foods has motivated them to reject the “Dutch tomato”, which they consider "artificial and insipid." In fact, between 1991 and 1992 the mean price fell about 28%.

Taking Spain as an example, since 30% of its production is in fresh tomatoes and 20% is exported, the "Mediterranean system" is different from the "Dutch system" in its more natural cultural practices, favored by more favourable climatic conditions. The Spanish tomato production system has a certain technological dependence on the "Dutch system" and a great heterogeneity in productive structures. The basic elements of the Spanish system are: field cultivation, or cultivation in soil under plastic or mesh-covered greenhouses without temperature or atmospheric control. Varieties exist for cultivation in sand-covered soils. Soilless cultivation is done on a small scale.

Mediterranean production in the last few years has undergone an important modernization programme. Outstanding changes include the adaptation of plastic greenhouses, the introduction of a localized irrigation system, the utilization of soluble fertilizers, varietal reconversion (Aldanondo Ochoa 1995; Diez Niclos 1995), automatization of the packaging line, and the incipient automatization of the irrigation system. A great part of these innovations were generated in the EU, especially in Holland.

One of the most important changes was created by hybrid varieties (Diez Niclos 1995). Their part in the non-utilization of MB well deserves a brief commentary. Holland maintained a monopoly on the production of the most-acceptable hybrids commercially, which were carriers of a resistance to the crop's gravest pathogens. This monopoly has gone on to be the patrimony of the "long-life" varieties, an Israeli patent which presents advantages over the Dutch varieties. “Llong-life" varieties contribute to a remarkable improvement in quality, firmness and homogeneity, although not so in flavour. It could be said that Israel has broken the seed market monopoly and has placed a new starting point in research. The qualities of these hybrids favour production areas at a distance from the market. It must be added that these "long-life" varieties at their commercial birth have been susceptible to pathogens, especially root-knot nematodes (*Meloidogyne* spp.) (Diez Niclos 1995; Tello & del Moral, 1995).

This brief analysis clearly intends what could be expressed in the following manner: the temptation to continue a technological strategy similar to that of the northern EU. Intensifying production systems to reduce unit costs may be inconvenient in the long run. The Mediterranean area enjoys relative prestige in the market place due to the naturalness of its crops (Tello 1984; Tello & Lacasa 1990; Tello & del Moral 1995).

TOMATO PRODUCTION IN SPAIN

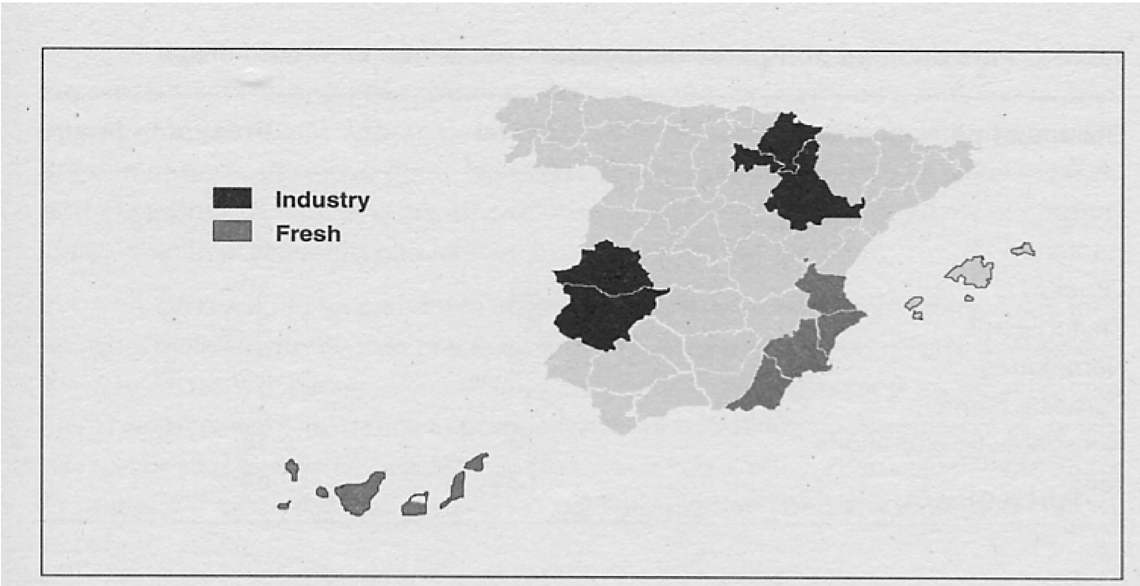
Tomato is a basic product in Spanish horticulture. It occupies 14% of the horticultural surface cultivated and contributes to 23% of the value of the sector's production. Spanish tomatoes satisfy the interior demand and have a strong export demand. About 25% of the fresh production and 50% of the canned fruit are exported. The details of production are found on Table 1, where data indicate an increase in unitary output, especially in fresh tomato, corresponding to a decrease in land cultivated (Aldanondo Ochoa 1995; Rodrfguez del Rincon 1995).

Table 1. Tomato production in Spain, 1983-1993 (Aldanondo Ochoa 1995)

TYPE	YEAR	HA (X 1000)	TONNES PER HA	TOTAL PRODUCTION
Tomato for fresh consumption	1983	43.1	39.2	1688.7
	1993	35.5	50.9	1805.9
Tomato for industrial transformation	1983	18.7	39.4	740.8
	1993	21.2	42.1	893.5

Spain's production areas are centered in the Southeast of the peninsula (Valencia, Alicante, Murcia and Almeria), the Ebro River Valley (Navarra, Rioja and Saragossa), Extremadura and the Canaries, which are areas in which 73% of the national production is concentrated (Figure 1).

Figure 1: Tomato production sectors in Spain



Nevertheless, crop systems are different. Extremadura and the Ebro River Valley are dedicated to production for canned tomatoes, sauce and paste. In this crop system, rotation every three years is habitual, a rotation that maintains tolerable disease levels, and where the use of MB has never been necessary. For this reason, these areas will not be considered in this paper (Aldanondo Ochoa 1995; Tello & del Moral,1995).

Southeastern Spain and the Canary Islands dedicate their fields to the production of fresh tomato. The crop system has been described in a previous paragraph on the "Mediterranean system." It will be commented on later from the point of view of pathosystems and soil disinfestation.

DISEASES IN SPANISH TOMATO CROPS

Diseases in tomato have undergone an important increase in the world. They have almost tripled in the last few years (Messiaen *et al.* 1991). A review of the papers published 20 years ago to prove that there were no more than thirty disease outbreaks. Today the figure is around 124 outbreaks as shown in Table 2, distributed among mycosis, bacteriosis, virosis, phytoplasmosis and non-parasitic diseases (Tello 1984; Tello & Lacasa 1990; Jorda Gutierrez 1995; Tello & del Moral 1995; Jorda & Llacer 1996; Lopez & Montesinos 1996).

Table 2: Parasitic and non-parasitic diseases described in tomato crops

GROUPS OF PATHOGENIC AGENTS	TOTAL	PRESENT IN SPAIN
Fungi	30	18
Bacteriae	7	6
Viruses	33	10

GROUPS OF PATHOGENIC AGENTS	TOTAL	PRESENT IN SPAIN
Phytoplasms	6	2
Nematodes	26	2
Parasitic plants	20	15
Total	**124**	**54**

Many of these new diseases have been described when the techniques for diagnosing them have improved, as is the case in virosis (Jorda 1995; Jorda & Llacer 1996). Others have appeared with the modification of cultural techniques (Tello & dell Moral 1995) such as the mycosis caused by *Spongospora subterrana* and *Calytella campanula* (Messiaen *et al.* 1991). Nevertheless, non-parasitic diseases reveal that new developments in crop management affect the appeareance of new pathologies. Non-parasitic diseases are confused with others caused by microbes which can result in harmful, if not counter-productive, phytosanitary provisions being put into action (Tello & del Moral 1995).

After years of observation, experience has demonstrated that MB is not effective in the soil for controlling bacteria, phytoplasms and virus, except when limiting the populations of the latter's vector agents, such as nematodes or fungi. Nor has it been recommended to control parasitic plants since they have no relevance to Spanish tomato crops (Messiaen *et al.* 1991). Therefore, the study of fungi and root-knot nematodes explains why the use of MB is insignificant in Spanish tomato crops.

FUNGI AND NEMATODES DISEASES: THEIR IMPORTANCE AND CONTROL

Table 3 outlines the inventory of fungi and nematodes described as tomato crop parasites. Of a total of 30 described, the presence of eighteen are registered in Spain whose presence does not indicate that they constitute a cause of appreciable losses (Tello & del Moral 1995).

Limiting ourselves to the pathogens that cause disease in the aerial part of the plant, the following observations must be made. *Erysiphe* spp and *Fulvia fulva* appeared superficially, without becoming more widespread with the passing of the years. On the other hand, *Alternaria dauciisp solanni*, *Botryotinia fuckeliana*, *Leveillula taurica* and *Phytophthora infestans* are responsible for important losses, regularly or sporadically, in spite of repeated and intense treatments with fungicides.

Soilborne fungi present in Spain deserve a longer commentary since they are what motivate disinfection practices with MB. As shown in Table 3, *Fusarium oxysporumisp lycopersici*, *Verticillium dahliae* and *Meloidogyne* spp are what have or have had a relevant incidence in production. Fortunately, the appearance of *Fusarium oxysporumisp radicis-lycopersici* over ten years ago produced an unjustifiable alarm "a posteriori" since this pathogen does not seem to have become more widespread (Tello & del Moral 1995).

At present, *Fusarium oxysporum fsp lycopersici* has two strains described in Spain (strain 0 and strain 1). Before hybrid cultivars with resistance to pathogens were introduced, it was one of the most important diseases, and compelled long cultural rotations (from 3-4 years) and soil disinfection. Resistant tomato hybrids permitted the escalation of fixed installations for production (irrigation, greenhouses, etc.), eliminating rotation. The combination of soil disinfection, generally based on metam sodium, and varieties with the resistant gene *I*, made the maintenance of an almost total control of mycosis possible for five years. The appearance of a new strain (strain 0) and its escalation compelled the introduction of varieties with gene *Is*, resistant to that pathogen. For 13 years since that time, the system has remained stable, in spite of continued crop intensification, with the consequent disappearance of traditional cultural tasks (Tello & Lacasa 1990; Tello & del Moral 1995).

Verticillium dahliae has shown a similar recent trend to that of *F.oxysporum fsp lycopersici* except for one important factor. The *Ve* gene introduced in the hybrid varieties, has remained stable for more than 20 years, without new fungal pathotypes being detected. It would be interesting to understand why new strains of *F.oxysporum fsp lycopersici* and *V. dahliae* have not appeared. The answer would permit a better understanding of the system and consequently, the extension of its use. In an empirical way, how some cultural techniques influence this, can be known by intuition.

Table 3: Pathogenic fungi and nematodes in tomato crops, their importance in Spain. Key (+) present; (-)not present; (1) acceptable control with phytosanitary products; (2) control with pesticides is difficult, making resistant varieties necessary.

SPECIES	PRESENT IN SPAIN	IMPORTANCE
Alternaria dauci fsp so/ani	+	1
A. tomato	-	-
A. alternata fsp lycopersici	-	-
Botryotinia fuckeliana	+	2
Calyptella campanula	-	-
Cercospora fuliginea	-	-
Colletotrichum atramentarium	+	-
C. gloeosporioides	-	-
C. acutatum	-	-
Didymella lycopersici	+	-
Erysiphe spp	+	-
Fulvia fulva	+	-
Fusarium oxysporum fsp lycopersici	+	2
F. oxysporum fsp radicis-lycopersici	+	-
F. solani	+	-
Leveillula taurica	+	2
Phoma destructiva	-	-
Phytophthora infestans	+	1
P. nicotianae var parasitica	+	-
Pyrenochaeta lycopersici	+	-
Pythium spp	+	-
Rhizoctonia solani	+	-
Sclerotium rolfsii	+	-
Sclerotinia sclerotiorum	+	-
Septoria lycopersici	-	-
Spongospora subterranea	-	-
Stemphyllium solani	-	-
St. botryosum fsp lycopersici	-	-
St. vesicarium	-	-
Verticillium dahliae	+	2
Meloidogyne spp	+	2

In root-knot nematodes of the genus *Meloidogyne*, the species most widespread in Spanish crops is *M. incognita* and *M. javanica*, where the situation has developed in a different way. The fragility of the hypersensibility Mi gene (chromosome 6) which loses its effectiveness at 32° C when in homocygosis and at 27° when in heterocygosis, provides insufficient protection during some seasons of the year (Messiaen *et al.* 1991; Tello & del Moral 1995). This circumstance makes soil disinfection treatments necessary. Nevertheless, recent experience acquired in Spain shows quite well that for such disinfections it is not necessary to revert to MB. Biofumigation and its combination with solarization, and even nematicides, have been shown to be sufficiently effective providing that the time and the technique for application are well known (Bello *et al.* 1998).

Nevertheless, recent concern about nematodes in tomato crops in some Spanish areas is not precisely over the lack of effectiveness of the /W/ gene, but rather over the fact that this gene is absent in present "long life" varieties. The most widespread varieties at the present time are shown in Table 4. A survey done during the summer of 1997 among 59 farmers from Almeria, dedicated for more than 10 years to tomato monoculture farming in greenhouses, and who use the above indicated cultivars, showed that 77% of their operations experienced difficulties with *Meloidogyne* spp.

Table 4: Resistance to soil pathogens in "long life" tomato for fresh consumption cultivated in Spain. Key: + = resistance incorporated; - = without resistance.

Cultivar Virus (ToMV)	*Meloidogyne* strain 0	*V.dahliae* strain 1	T. Mosaic	F.o. fsp	*lycopersici*
CLX-3759 F1	-	+	+		+
Daniela F1	-	+	+	+	+
Durinta F1	-	+	+	+	+
E-873 F1	-	+	+	+	+
E-875 F1	-	+	+	+	+
Gabriela	+	+	+	+	+

One interpretation of these data is the following: The escalation of the "long life" varieties of tomato lacking the *Mi* gene resistant to *Meloidogyne spp*, has caused problems in the soil that have remained at bearable levels with resistant varieties. When those cultivars incorporate the *Mi* gene, as in the case of the Gabriela variety, as indicated in Table 4, the situation will again be restored that was reached with hybrids without the "long life" gene.

CONCLUSIONS

Three conclusions made to explain the reason why MB is not used for tomato production in Spain:

1. There are a small number of pathogens that cause relevant losses in Spanish tomato crops. The reason must be looked for in the "more natural" form of tomato production when compared with other countries of the European Union. The superior quality of the Mediterranean tomato is a reputation well-earned by Spain in the European markets. This quality is a consequence of a "more natural" form of production.
2. The absence of MB in practically all of Spain's tomato crops could be explained by the stability of the genes resistant to *Fusarium oxysporum fsp lycopersici*, *Verticillium dahliae* and *Meloidogyne* spp. which has been verified in the last 20 years. The durability of the effectiveness of the resistant genes has been influenced by crop management, both because an important part of the surface area applies Almeria's type of "sand-covered soils", and because of soil disinfectants, essentially based on methyl-isothiocyanate.
3. "Long life" hybrid varieties are susceptible to *Meloidogyne* spp. due to their lack of the /W/ gene. Alternative control techniques based on biofumigation, alone or combined with solarization, and the use of nematicides developed in Spain, have demonstrated their utility when correctly applied. In any case, the introduction of the /W/ gene in "long life" hybrids has begun. Varieties with that property are offered on the seed market. This circumstance will predictably restore the situation to that generated by previous hybrid cultivars.

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ALTERNATIVES TO METHYL BROMIDE FOR TOMATO PRODUCTION IN THE MEDITERRANEAN AREA

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ABSTRACT

In the Mediterranean area, tomato soilborne pathogens used to be controlled by methyl bromide, particularly in protected cultivation. To decrease the use of this fumigant, non-chemical and chemical alternatives were developed and implemented in many Mediterranean countries. However, the success of the alternative depends on the degree of its integration in an integrated pest management programme.

Keywords: Methyl Bromide, tomato, alternatives, Mediterranean countries.

DEFINITION OF METHYL BROMIDE ALTERNATIVES

The MBTOC report (UNEP 1998) defined alternatives as: “Those non-chemical or chemical treatments and/or procedures that are technically feasible for controlling pests, thus avoiding or replacing the use of Methyl Bromide (MBr)”. “Existing alternatives” are those in present or past use in some regions, “Potential alternatives” are those in the process of investigation or development".

ALTERNATIVES TO METHYL BROMIDE FOR TOMATO PRODUCTION

The existing and potential alternatives to methyl bromide (MB) in the Mediterranean countries to control tomato soilborne pathogens pest are reported in Table 1.These alternatives should be considered as components of an Integrated Pest Management (IPM) programme which includes other control methods such as sanitation, pathogen-free seeds and seedlings, weed control, improvement of plant growing conditions and other similar activities (UNEP 1998).

Non chemical alternatives

Resistant varieties

Many tomato cultivars are resistant to various soilborne pathogens. However, at the moment, no resistance is available for the control of some pathogens such as *Sclerotinia sclerotiorum*, *Didymella lycopersici* , *Verticillium dahliae* race 2, *Fusarium oxysporum* f.sp. *lycopersici* race 3, *Fusarium oxysporum radicis - lycopersici*, *Pyrenochaeta lycopersici*, *Clavibacter michiganensis* subsp. *michiganensis*, *Pseudomonas syringae* pv. tomato and *Xanthomonas campestris* pv. *vesicatoria*. Most of the high yielding tomato hybrids used in many Mediterranean countries are susceptible to nematodes. Even for the available resistant cultivars, the rise of new races particularly of *Fusarium* and *Verticillium* is a threat to tomato production. Soil and water salinity increase the susceptibility of tomato plants to many diseases and particularly to *Fusarium* and *Verticillium* wilts. Resistant varieties become also susceptible when the irrigation water has a high salt content (Gabarra § Besri, 1999, Besri 1999, Besri 2000).

Grafting

Resistant rootstocks, provide excellent control of many tomato soilborne pathogens and particularly *Fusarium oxysporum* f. sp. *lycopersici*., *F. oxysporum* f. sp. *radicis-lycopersici*, *P. lycopersici* and *Meloidogyne* spp. This technique, which initially was considered too expensive, is now widely used at a commercial level in many Mediterranean countries. In general, without grafting, the tomato plant density per hectare is about 18,000 plants. When grafted plants are used, the same yield could be obtained with half plant population (9,000 plants/ha). In addition to controlling some soilborne pathogens, tomato grafting promotes growth, increases yield, increases plant tolerance to low temperature, extends the growth period and improves fruit quality (Besri 2000).

Organic amendments

Biofumigation with organic matter such as brassicae, compositae, swine and chicken manure, grape and olive pomace produces volatile chemicals (methyl isothiocyanate, phenethyl isothiocyanate) which have herbicidal, fungicidal, insecticidal and/or nematicidal properties (Gamliel 2000 b). Marigolds (*Tagetes spp.*) have a high suppressive effect on nematode populations. Differences, however, exist between the various species of *Tagetes* in their ability to effectively reduce nematode populations (Besri 2000, Reiss 1998).

Soil less culture

In the Mediterranean countries, many farmers have introduced soilless culture for vegetables and particularly for tomatoes as a replacement for MB fumigation. However, although soilless media are usually pathogen-free, infestation of these media by plant pathogenic micro-organisms such as *Phytophthora, Pythium, Rhizoctonia* and *Fusarium* may occur in greenhouses if proper sanitation procedures are not followed (Jenkins § Averre 1983).

Table 1: Technical Evaluation of the degree of development and the efficacy of Methyl Bromide alternatives for the control of tomato soilborne pathogens.

ALTERNATIVE	Degree of development[1]	EFFICACY			
		Spectrum of activity		Environmental dependence	
		Specific	Broad	Low	High
NON-CHEMICAL					
Resistant varieties	4	■			■
Resistant rootstocks	4	■			■
Organic amendments	4	■		■	
Biofumigation, compost, cover crops	3	■		■	
Soilless culture	4		■		■
PHYSICAL TREATMENTS					
Solarisation	3	■			■
Steam	4		■	■	
Flaming	3	■		■	
Biological control	2	■			■
CHEMICAL					
Metam Sodium	4		■		■
Dazomet	4		■		■
1,3-D	4	■			■
Chloropicrin	4	■		■	
TREATMENT COMBINATIONS					
Chemical x chemical	4		■		■
Chemical x non-chemical	4		■	■	
Non-chemical x non-chemical	4	■		■	

1: At experimental stage in laboratory, 2: At experimental stage in field, 3: At small scale, 4: At commercial level. Adapted from UNEP (1998)

Physical treatments

Solarization

Soil solarization controls many tomato pathogens (Stapleton 2000, Tjamos 2000). Though initially used only in hot regions during the summer, technological advances are extending its applicability to cooler areas such as the northern part of Italy (Stapleton 2000, Tamietti § Valentino 2000). Another application for which solarization has become common is for disinfestation of seedbeds, containerized planting media, cold-frames and tomato supports (Besri 1991, Stapleton 2000). However, despite its efficiency, soil solarization is used only on a relatively small scale as a substitute for MB.

Steam

Steaming is a well established and effective technique for soilborne pest control and is extensively used for bulk soil, soil treatments within green house. Negative pressure steam technology currently available improves energy efficiency by providing better dispersal of the steam throughout the soil and reducing treatment time. Steam is used in many Mediterranean countries in the greenhouse industry with vegetables and ornamental crops to replace MB (UNEP 1998, Runia 2000).

Flaming

In the Mediterranean area, *Orobanche ramosa* and *O. aegyptiaca* are very important parasitic higher plants on many vegetables and particularly on tomato. No variety of tomato resistant to these parasites is known. Preliminary experiments have shown that burning the *Orobanche* plants at the end of the growing season decreases the *Orobanche* seed population in the soil and consequently the parasite incidence and severity on the following crop (Besri 1999, Gabarra § Besri 1999).

Biological control

Biological control of tomato soilborne pathogens is gaining an increasing interest. *Penicillium oxalicum* reduces the incidence of *F. oxysporum* f.sp.*lycopersici* both in hydroponic and soil systems. *Trichoderma harzianum* and *T. Koningii* control *Fusarium* root and crown rot. The introduction into the soil of non-pathogenic strains of *F. oxysporum* (F.O.74) obtained from suppressive soil controls *Fusarium* wilts. However despite decades of research in the field of biological control, only a few micro-organisms are on the market and are successfully applied in practice (Vannacci and Gullino 2000).

Chemical alternatives

Chloropicrin (CP) is a very effective fungicide for the control of tomato soil-borne fungi, but not for weed and nematodes control. 1,3 Dichloropropene (1,3-D) is as efficacious as MB in controlling nematodes, but does not control fungi or insects. At high rates, 1,3-D has some efficacy against few weeds. Dazomet and metam-sodium applied to moist soil decompose to methyl isothiocyanate which is the biocidal agent. These chemicals do not provide consistent control of soilborne pathogens comparable to MB (Braun and Supkoff 1994).

Combination of alternatives

Non chemical x Chemicals

Crop rotation in combination with metam sodium applied through the drip irrigation system, is successfully used in protected cultivation to control some tomato soil-borne pathogens. The rotation adopted on a 3-year basis includes melon, pepper (hot and sweet), peas, cucumber, tomato and squash (Besri 2000). The combination of soil solarization with reduced dosage of Dazomet and of MB controls *Fusarium* and *Verticillium* wilts and *Fusarium* crown rot on tomato (Minuto *et al.* 2000, Gamliel *et al.* 2000a). Soil solarization alone or combined with low rates of 1,3-D, dazomet or MB control efficiently both nematodes and weeds and significantly increased marketable yield (Di Vito et al 2000) . The use of virtually impermeable plastic film (VIF) improved the efficacy of Dazomet (Minuto *et al.* 2000).

Non chemical x non chemicals

Biofumigation considerably shortens the time necessary to accomplish acceptable pest control through solarisation (Gamliel et al 2000b). Combination of reduced length of soil solarization and soil drenching of K. 165 (*Paenibacillus* sp.) effectively controls *F.oxysporum* f.sp. *radicis cucumerinum* in comparison with metam sodium treatment (Tjamos 2000).

Combination of chemicals

Metam-sodium, CP, 1,3-D, 1,3-D plus 17% CP (1,3-D+C-17) and 1,3-D plus 35% CP (1,3-D+C-35) control efficiently various tomato soil borne pests (Csinos *et al.* 2000).

CONCLUSION

In the Mediterranean countries, alternatives to MB for tomato production are available. These alternatives developed to control the key pests have been adopted in an IPM programme by farmers who are technically-aware and who are also on the watch for any new technology regardless of its cost. However, in the Mediterranean countries, many factors are limiting a wider application of MB alternatives. The most important are: an impression of complexity of the proposed methods, inadequate information, the low cost of MB, the activities and dynamism of the chemical companies, the weakness of the ecological demand, and the lack of specialists and extensionists in IPM.

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ALTERNATIVES TO METHYL BROMIDE FOR VEGETABLE PPRODUCTION IN GREECE

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ABSTRACT

Soil solarization with impermeable plastics singly or in combination with biocontrol agents or chemicals is efficient under Greek climatic conditions in reducing the duration of soil coverage from 4-6 down to 3 weeks and controlling equally effectively serious soilborne pathogens. This could be considered as an alternative to methyl bromide**.**

INTRODUCTION

Vegetable production in Greece has been largely dependent on the use of methyl bromide (MB) for several decades now. However, MB will not be available in the market anymore. Greek climatic and farming conditions favour theh use of soil solarization as a MB alternative for controlling soilborne pathogens in vegetable crops. Although the classical 4-6 weeks soil solarization is effective, its extensive commercial application has been prevented both in Greece and elsewhere.

Application of soil solarization during the last 25 years in Greece was effective in restricting development of disease symptoms and increasing yield with drastic reduction in the density of fungal propagules in vegetables {Antoniou *et al.* 1993 1995ab 1997; Tjamos 1983, 1991, 1992, 1998; Tjamos & Faridis 1980, 1982; Tjamos & Paplomatas 1988; Tjamos *et al.* 1987 1989, 1992). More recent data demonstrated that reduced duration of soil solarization singly or in combination with low doses of MB significantly restricted the populations of *Fusarium oxysporum* f.sp. *cucumerinum* of cucumbers even one week after mulching, while fungal populations were almost eliminated after 2-4 weeks solarization (Tjamos *et al.* 2000). A drastic reduction and even elimination of the number of sclerotia of *Pyrenochaeta lycopersici* was also demonstrated within one to two weeks after soil tarping (Tjamos *et al.* 2000b). It has been demonstrated that heat tolerant fungal or bacterial antagonists are involved in the long-term effect of soil solarization for 2-3 cropping seasons.

Soil solarization against *Verticillium dahliae* of tomatoes and globe artichokes and *Clavibacter michiganensis* subsp. *michiganensis* of tomatoes in Greece indicated that heat tolerant fungal (e.g. *Talaromyces flavus*) or bacterial antagonists (e.g. *Paenibacillus* and *Bacillus*) were involved in the longevity of the effect (Tjamos & Paplomatas 1989; Antoniou *et al.* 1993; Tjamos *et al.* 2000).

Our current work on solarization in Greece is mainly focused on the effectiveness of reduced duration treatments using impermeable plastics (polyamide plastic sheets covered with polyethylene), singly or in combination with biological or chemical agents.

COMBINATION OF REDUCED LENGTH SOIL SOLARIZATION WITH IMPERMEABLE PLASTICS AND BIOCONTROL AGENTS

Soil solarization trials were established in Peloponesse region to determine whether a short period of solarization using a triple layer plastic sheet of 40 μm thick. The plastic sheet consisted of two outer layers of common polyethylene and one of polyamide plastic sheet in the middle.

The effect of reducing the length of soil solarization combined with the use of selected K-165 antagonistic isolates against *Fusarium oxysporum* f. sp. *radicis-cucumerinum* of cucumbers, was tested in plastic houses, where cucumbers were grown in Peloponesse in South-West Greece. Experimental trials were established in very infested soils with intense symptoms during the previous cropping season. Short duration solarization (covering with impermeable plastics for 17 instead of 30-45 days and combined with a post planting root drench of K-165) was compared with disinfestation with metam-sodium at a dose of 1.2 l/m^2.

The combination of reduced length soil solarization and soil drenching of a *Paenibacillus* strain K-165 effectively controlled *F. oxysporum* f.sp. *radicis-cucumerinum*. The final percentatge of diseased plants was 0.7% compared with metam-sodium treatments of 11%. The total yield of cucumbers reached 31 tonnes/ha in solarized soils plus the antagonist, in comparison with the metam-sodium treated soils where the yield was 24 tonnes/ha (Tjamos *et al.* 2000).

COMBINATION OF REDUCED LENGTH OF SOIL SOLARIZATION WITH NEMATOCIDES

The main soilborne pathogens of tomato cultivations in Greece are *Pyrenochaeta lycopersici, Fusarium oxysporum* f.sp. *radicis lycopersici, Verticillium dahliae, Phytophthora* sp. and bacterial canker *Clavibacter michiganensis* subsp. *michiganensis*. Furthermore *Meloidogyne* sp. is becoming a limiting factor, particularly for summer plantations.

Experimental trials were carried out for the control of the main tomato soilborne pathogens for two consecutive cropping seasons. Trials started in July 2000-May 2001 for the first period and August 2001 to January 2002 for the second period.

A three-week soil solarization treatment was applied during July 2000 in tomato plastic houses by using two types of impermeable plastics singly or in combination with nematocides and/or fumigants. Five plastic house plots were covered with Orgafum® 33-33-33 containing 33% polyamide and another five with Orgafum ®40 25-50-25 with 50%. Experimental plastic house plot (40X5 m) were planted with the Jumbo tomato hybrid in January 2001, while 450 plants per plot were planted**.**

RESULTS

First cropping season July 2000-May 2001

Soil temperature determination in covered and uncovered soil showed that there was difference at various soil depths between the two types of plastics (50°C at 5-10 cm soil depth) while in the control uncovered sites temperature was 10-12°C lower. Plantations were frequently inspected for soilborne pathogen infections. Table 1 reports very restricted symptom development in all treatments and trials.

Table 1: Effectiveness of soil solarization singly or in combination with nematocides on the percentage of diseased tomato plants and the final total tomato fruit yield per plant in 8 experimental plastic houses

Soil treatments	Soil borne pathogen	Percentage of diseased plants[5]	Yield[6] Kg /plant
Orgafum ®40[1]			
SS[3] 3 Weeks + Condor 200 L/ ha	*Meloidogyne sp.*	0.22	*4.49*
SS 3 Weeks + MB[4] 250 Kg/ ha	*Clavibacter michiganensis* subsp. *michiganensis*	0.22	*4.23*
SS 3 Weeks	*Clavibacter michiganensis* subsp. *michiganensis*	0.22	*4.06*
SS 4 Weeks	*Pseudomonas* sp. Pith necrosis	0.22	*3.81*
SS 3 Weeks + Rugby 20 L/ ha	*Phytophthora* sp.	0.22	*3.82*
Orgafum ®35[2]			
SS 3 Weeks + Condor 200 L/ ha	*Clavibacter michiganensis* subsp. *michiganensis*	0.44	*4.14*
SS 3 Weeks + MB 250 Kg/ ha	*Pyrenochaeta lycopersici*	0.22	*4.01*
SS 3 Weeks	*Healthy plants*	0.0	*3.92*
SS 4 Weeks	*Pseudomonas* sp. Pith necrosis	0.22	*3.70*
SS 3 Weeks + Rugby 20 L/ ha	*Healthy plants*	0.0	*3.88*

[1] impermeable plastic sheet (polyethylene 25: polyamide50: polyethylene25); [2] impermeable plastic sheet (polyethylene33: polyamide33: polyethylene33); [3] Soil solarization [4] Methyl Bromide[5] Mean of 450 plants[6] Mean of 450 plants

Indeed all treatments were very effective against the main tomato soilborne pathogens. It is remarkable that at the end of the cropping season just 1 or 2 out of 450 plants developed symptoms of the above mentioned diseases, a figure quite negligible proving the effectiveness of the applied methods. No difference were observed in the effectiveness among the plastics. Early and late infection by *Pyrenochaeta lycopersici* in nearby control untreated plots almost reduced total tomato fruit yield by 40% and reduced mean yield to 2 -2.5 kg/ plant.

Second cropping season August 2001-January 2002

The same plots were also used for a second cropping season between August 2001-January 2002 without any soil treatment. The only difference with the previous season was the use of plants grafted on *Meloidogyne* tolerant rootstocks.

Table 2: Effectiveness of soil solarization one year after its application on the percentage of diseased tomato plants in 8 experimental plastic houses

Soil treatments	Soil borne pathogen	Percentage of Meloidogyne diseased plants[5]
Orgafum®40[1]		
SS[3] 3 Weeks + Condor 200 L/ ha	*Meloidogyne*	5
SS 3 Weeks + MB[4] 250 Kg/ ha	*Meloidogyne*	3
SS 3 Weeks	*Meloidogyne*	2.5
SS 4 Weeks	*Meloidogyne*	2.6
SS 3 Weeks + Rugby20 L/ ha	*Meloidogyne*	3.0
Orgafum®35[2]		
SS 3 Weeks + Condor 200 L/ ha	*Meloidogyne*	5.5
SS 3 Weeks + MB 250 Kg/ ha	*Meloidogyne*	2.8
SS 3 Weeks	*Meloidogyne*	2.7
SS 4 Weeks	*Meloidogyne*	3.2
SS 3 Weeks + Rugby20 L/ ha	*Meloidogyne*	3.1

[1] Impermeable plastic sheet (polyethylene 25: polyamide50: polyethylene25); [2] impermeable plastic sheet (polyethylene33: polyamide33: polyethylene33); [3] Soil solarization [4] Methyl Bromide[5] Mean of 450 plants

Data in Table 2 strongly suggest a long-term effect of solarization exceeding not only soilborne fungal or bacterial pathogens but also nematodes. Observations in nearby plantations of the same variety and same age were infected by rootknot nematodes up to 80%.

CONCLUSIONS

Soil solarization with impermeable plastics was efficient in almost nullifying the percentage of diseased plants during the first cropping season (winter-spring). Mean total tomato fruit production per plant and treatment did not differ more than 15%. No difference among 3 and 4 weeks solarization was observed, proving that 3 weeks solarization was more than enough when impermeable plastics were used. No significant differences among plastics was observed. No *Meloidogyne* infection was observed but we are dealing with twinder spring cultivation. During the second cropping season all treatments significantly inhibited root infection by *Meloidogyne* indicating a long-term effect of the method.

It seems that reduced duration of solarization using impermeable plastics could be one of valuable alternatives to MB fumigation in Greece. Research should continue to assess a combination of antagonistic organisms with soil solarization. It is possible that the duration of solarization could be further reduced if properly combined with nematocides and or other available fungicides.

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ALTERNATIVES TO METHYL BROMIDE IN SWEET PEPPER CROPS IN SPAIN

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ABSTRACT

In the Southeast of Spain over 9,000 ha of sweet pepper are grown in greenhouses. Of this land area, 1,880 ha are disinfected every year with MB (MB 98:2) to control *Phytophthora capsici* and *Meloidogyne incognita* and to mitigate against replant disease. Some alternatives to replace MB by 2005 were studied between 1997 and 2001. MB (98:2) at 30 g/m^2 applied under VIF (Virtually Impermeable Film) plastic provided the same results as MB at 60 g/m^2 applied with polyethylene (PE) plastic. However, at 16 g/m^2 with VIF plastic, pathogen control decreased and there was a yield reduction of more than 20% from the second year onwards. Dichloropropene (60.5%)+chloropicrin (33.3%) mixture applied by drip irrigation at 50 g/m^2 under PE plastic produced similar results to MB and may be a short term alternative to MB. Biofumigation with solarization, using fresh sheep manure and chicken manure or soybean flour, gave satisfactory pathogen control and production similar to MB. When the applications were repeated there was an improvement in efficacy against pathogens, yield and physico-chemical characteristics of the soil. This has proven to be a viable alternative for sustainable and organic agriculture. Grafting is another alternative which provides satisfactory soil-borne pathogen control and acceptable yield.

INTRODUCTION

In Spain, the cultivation of greenhouse sweet pepper is located in the Southeast. In 2000, 7,000 ha were grown in Almeria, 1,440 ha in Murcia and 440 ha in Alicante.

Soil growing pepper in Murcia and Alicante is disinfected every year with methyl bromide (MB 98:2), to control *Phytophtora capsici* and *Meloidogyne incognita* (Tello and Lacasa 1997; Bello *et al*. 1997; Lacasa *et al*. 1999). In these regions, replant disease was thought to be caused by production of pepper crops in the same soils for more than fifteen years (Lacasa and Guirao, 1997), and annual soil disinfection avoided production loss (Lacasa *et al*. 1999, 2000; Guirao *et al*. 2001). In the province of Almeria, MB is not used for soil disinfection because pepper is not only grown in the winter cycle but also because of the characteristics of the soil, the growing systems and frequent crop rotation.

Regulation EC2037/00 from the European Parliament and Council prohibits the use of MB for soil disinfection from December 31th 2004 which, without alternatives to MB, puts at risk the continuity of pepper cultivation in Murcia and Alicante that directly employs 3,569 growers and another 6,000 people indirectly (López and Guirao, 1998).

At the end of 1996, the Federación de Cooperativas Agrarias de Murcia (FECOAM) and the Consejería de Agricultura, Agua y Medio Ambiente de la Región de Murcia, joined in a programme to develop alternatives to MB in greenhouse sweet pepper crops. By mid-1997, the Instituto Nacional de Investigaciones Agrarias (INIA) approved the national interest research project INI SC97-130-C3 to investigate alternatives in crops using MB, including sweet pepper grown in greenhouses of the Southeast of Spain (Bolivar 1997).

From 1997 to 2001, various chemical products and non-chemical methods for soil disinfection were studied. The trials were carried out in commercial pepper greenhouses with different phytopathological problems and different levels of crop repetition. The alternatives were compared with MB (98:2) applied at 60 g/m^2 under 0.05 mm PE plastic, MB at 30 g/m^2 under 0.04 mm VIF or non-treated soil. The effects were evaluated by examination of *P. capsici* and *M. incognita* incidence, plant development, yield and weed proliferation. Each alternative was assayed in at least three greenhouses. Treatments were randomized in a complete block design with three replicates. The viable alternatives were trialled over three consecutive years in the same greenhouse.

CHEMICAL ALTERNATIVES

Methyl bromide rate reduction

Rates to achieve pathogen suppression using reduced rates of MB will be trialled until 2005. Formulations of MB 98:2 and MB 67:33 were used to make the equivalent 60 g/m^2, 30 g/m^2, 15 g/m^2 rates of MB 98:2. Fumigations were applied using VIF plastic for the 30 and 15 g/m^2 rates. Repeat trials were done in one greenhouse and the efficacy trials were carried out in greenhouses with *P. capsici* and *M. incognita* problems.

The same efficacy was observed at 30 g/m^2 under VIF plastic as at 60 g/m^2 using PE, both in greenhouses with phytopathological problems (Table 1) and when an application was repeated (Table 2). MB 98:2 at 15 g/m^2 did not provide satisfactory *P. capsici* control and the yield loss increased (higher than 18%) (Table 1) when the application was repeated (Table 2).

Table 1: Efficacy of application in MB reduced rates. Average of three assays carried out in 1997-1998.

	Percent plants with *P. capsici*	**Percent plants with *M. incognita***	**Average knot index[1]**	**Plant height (cm)**	**Marketable yield (kg/m^2)**	**Weed index (1-3)**
MB 60 PE	7.7 a	12.5 a	0.23 a	122.6 a	9.4 a	0.3 a
MB 30 VIF	12.6 a	6.3 a	0.10 a	121.7 a	8.9 a	0.2 a
MB 15 VIF	19.5 b	2.7 a	0.65 a	108.8 b	7.2 b	0.5 a
Control	53.4 c	62.5 b	3.70 b	81.5 c	3.3 c	2.6 b

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. [1]According to Bridge and Page (1980).

Table 2: Effect of the reiterated use of MB reduced rates. Average of the three replicates in the same greenhouse.

	1997/98			1998/1999			1999/2000		
	[1]Average knot index	Plant height (cm)	Marketable yield (kg/m^2)	Average knot index	Plant height (cm)	Marketable yield (kg/m^2)	Average knot index	Plant height (cm)	Marketable yield (kg/m^2)
MB 60 PE	0.0 a	142.5 a	12.5 a	0.0 a	101.3 a	8.8 a	0.0 a	92.5 a	9.2 a
MB 30 VIF	0.0 a	144.2 a	12.0 a	0.0 a	103.3 a	8.9 a	0.0 a	93.8 a	9.5 a
MB 15 VIF	0.0 a	131.3 b	10.6 b	0.0 a	96.6 b	7.3 b	0.1 ab	88.8 b	8.0 b
Control	0.5 b	107.7 c	6.7 c	0.5 b	75.0 c	3.2 c	0.8 b	65.0 c	3.5 c

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. [1]According to Bridge and Page (1980).

BROAD SPECTRUM ACTION FUMIGANTS

Alternatives assayed were: Chloropicrin at 50 g/m^2 applied through the drip irrigation system under PE plastic, four trials; Metam sodium (50 LS) at 150 g/m^2 applied in irrigation water under PE plastic, three trials; Dazomet (Basamid 98 GR) at 60 g/m^2 applied on soil at 60% of the field capacity, buried and covert with PE; 1,3-dichloropropene (1,3-D, 60.5%) with chloropicrin (33.3%) at 50 g/m^2 applied in irrigation water with PE plastic, 10 trials; and 1,3-D (60.5%) with chloropicrin (33.3%) at 50 g/m^2 applied on the soil over several consecutive years.

Chloropicrin and 1,3-D+chloropicrin had efficacies similar to MB 98:2 at 60 g/m^2 (Table 3). However, pathogens control was variable. When metam sodium or Dazomet were used there was a significant reduction in pathogen control and yield (Table 3). When the application of Telopic was repeated in the same soil, yield, plant development, weed control and *P. capsici* incidence were not significantly different from MB 98:2 at 60 g/m^2. The incidence of *M. incognita* with Telopic was significantly higher than MB 98:2 at 60 g/m^2, although variable through the years (Table 4).

Table 3: Application efficacy of different products as alternative to MB. Average of 1997/98, 1998/99, 1999/00 assays.

	Percent plants with *P. capsici*	Percent plants with *M. incognita*	Average knot index[1]	Plant height (cm)	Marketable yield (kg/m^2)	Weed index (1-3)
MB 60 PE	7.7 a	12.5 a	0.2 a	114.1 a	8.0 a	n.e
Cloropicrin	9.1 a	22.2 a	0.6 a	118.5 a	7.4 a	n.e
Control	53.4 b	62.5 b	3.7 b	81.5 b	3.3 b	n.e
MB 60 PE	6.9 a	8.3 a	0.1 a	154.9 a	7.6 a	0.5 a
Metam Na	30.1 b	63.0 b	2.6 b	130.3 b	6.6 b	1.5 b
MB 60 PE	8.9 a	15.3 a	0.7 a	86.0 a	6.8 a	n.e
Dazomet	18.5 b	54.2 b	2.3 b	76.0 b	5.0 b	n.e
Control	25.1 c	55.5 b	2.1 b	74.0 b	5.2 b	n.e
MB 60 PE	1.4 a	5.1 a	0.1 a	143.5 a	9.3 a	0.1 a
Telopic	6.8 a	21.1 b	0.5 a	137.3 a	9.4 a	0.1 a
Control	36.5 b	55.2 c	2.5 b	88.8 b	4.4 b	0.8 b

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. [1]According to Bridge and Page (1980); n.e = non tested.

NON-CHEMICAL ALTERNATIVES

Biofumigation with solarization

The following were trialled:

- Timing of the organic amendments and solarization, beginning in August, September, October or November. Fresh sheep manure (EFO) (7kg/m^2) plus chicken manure (3 kg/m^2) and 3-6 weeks of solarization. Three assays.
- Type of amendment. EFO (7 kg/m^2) plus chicken manure (3 kg/m^2); EFO (7 kg/m^2) plus soybean flour (0,5 kg/m^2); EFO (7 kg/m^2) plus urea (0.25 kg/m^2) and 4-6 weeks of solarization. Two assays.
- Biofumigation with solarization (B+S) reiterated in the same soil. 1st year: 7kg/m^2 of EFO plus 2.5 kg/m^2 of chicken manure; 2nd year: 5 kg/m^2 of EFO plus 2.5 kg/m^2 of chicken manure; 3rd year: 4 kg/m^2 of EFO plus 2 kg/m^2 of chicken manure.

Table 4: Effect of the reiterated application of Telopic in the same soil through three consecutive years.

YEAR	Treatment	Percent plants with *P. capsici*	Average knot index[1]	Plant height (cm)	Marketable yield (kg/m^2)	Weed index (1-3)
1st year 1998/99	MB 60	0.4 a	0.1 a	130.1 a	8.5 a	0.05 a
	Telopic	2.4 a	0.2 a	124.5 a	8.9 a	0.08 a
	Control	25.3 b	3.1 b	89.0 b	4.3 b	1.0 b
2nd year 1999/00	MB 60	0.6 a	0.1 a	113.1 a	7.8 a	0.2 a
	Telopic	2.5 a	0.7 a	115.3 a	8.4 a	0.1 a
	Control	34.7 b	2.5 c	73.5 b	3.2 b	1.1 b
3rd year 2000/01	MB 60	1.5 a	0.6 a	143.5 a	9.1 a	0.05 a
	Telopic	3.8 a	2.8 b	149.7 a	9.2 a	0.05 a
	Control	27.4 b	6.7 c	80.1 b	3.0 b	4.6 b

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. [1]According to Bridge and Page (1980)

Table 5: Effect of timing in biofumigation plus solarization.

	Percent plants with *P. capsici*	Percent plants with *M. incognita*	Average knot index[1]	Plant height (cm)	Marketable yield (kg/m^2)	Weed index (1-3)
MB 60	0.2 a	8.3 a	0.1 a	132 a	9.9 a	0.3 a
Biof.+ sol. Aug	5.6 b	66.6 b	3.3 b	125 a	9.4 a	2.1 b
Control	72.1 c	97.0 c	5.5 c	91 b	4.2 b	2.8 c
MB 60	(1) -	0.0 a	0.0 a	181 a	12.2 a	0.1 a
Biof.+ sol Sept.	-	8.0 b	0.2 a	179 a	12.0 a	1.1 b
Control	-	24.0 c	2.1 b	157 b	11.1 b	1.6 b
MB 60	(1) -	0.0 a	0.0 a	180 a	12.3 a	0.2 a
Biof.+ sol Oct.	-	9.0 b	0.3 a	176 a	10.6 b	2.1 b
Control	-	26.0 c	2.2 b	156 b	11.0 b	1.7 b
MB 60	0.5 a	8.6 a	0.1 a	171 a	8.4 a	0.6 a
Biof.+ sol. Nov	13.2 b	44.4 b	1.2 b	129 b	6.9 b	1.9 b
Control	28.6 c	96.2 c	4.0 c	136 b	6.3 b	2.8 c

(1) No *P. capsici* in the greenhouses. Means in the same column followed by the same letter are not significantly different ($P > 0.05$). LSD Test.
[1]According to Bridge and Page (1980)

B+S initiated before mid September had results similar to MB (Table 5), both in marketable fruit and plant development. Pathogen and weed control were significantly lower with B+S than with MB. When B+S was initiated after mid-September, the results were poorer as the applications were delayed (Table 5). The best results were obtained using soybean flour as an organic amendment to keep optimal C/N levels during the B+S process (Table 6). The reiteration of B+S resulted in improved pathogen and weed control, as well as in the physico-chemical soil properties, with yield similar to that of MB (Table 7).

Table 6: Effect of biofumigation + solarization (B+S) using different nitrogen amendments.

	Percent plants with *P. capsici*	Percent plants with *M. incognita*	Average knot index[1]	Plant height (cm)	Marketable yield (kg/m^2)	Weed index (1-3)
MB 30	0.0 a	26.1 a	0.7 a	108.0 a	9.7 a	0.4 a
B+S(EFO+chicken manure)	2.6 b	25.3 a	0.6 a	92.5 b	8.6 b	0.6 a
B+S(EFO + soybean flour)	0.2 a	26.0 a	0.8 a	89.0 b	9.6 a	0.5 a
B+S (EFO + urea)	1.5 b	21.7 a	0.5 a	87.5 b	8.1 b	0.5 a

Means in the same column followed by the same letter are not significantly different ($P > 0.05$). LSD Test. [1]According to Bridge and Page (1980)

Table 7: Effect of the reiterated application of biofumigación + solarization (B + S) (greenhouses without *P. capsici*).

	Percent plants with *M. incognita*	Average knot index[1]	Plant height (cm)	Marketable yield (kg/m^2)	Weed index (1-3)
MB 30	36.7 a	1.5 a	164.3 a	11.2 a	0.1 a
B + S 1st year	90.0 b	4.5 b	151.0 b	10.0 b	1.0 b
B + S 2nd year	43.3 a	1.8 a	150.2 b	11.3 a	0.4 a
B + S 3rd year	40.0 a	1.3 a	153.1 b	11.2 a	0.2 a
Control	100.0 b	6.7 c	143.0 c	9.3 b	3.0 c

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. [1]According to Bridge and Page (1980)

Grafting

Capsicum annum rootstocks with different level of resistance to *M. incognita* and *P. capsici* were used. The responses of 78 rootstocks, mostly *C. annum* x *Capsicum* ssp. hybrid, were studied. Some of the rootstocks gave satisfactory pathogen control and production similar to MB (Table 8). The repetition of the same rootstock in the same soil over 3 years selected more aggressive populations of *M. incognita*. Therefore, it will be necessary to develop rootstock management strategies that counter resistance by, for example, using grafted seedlings in B+S soil, or by treating the soil with broad spectrum chemicals with specific or partial action.

Table 8: Response of different rootstocks used for grafting. Three assays.

	Percent plants with *P. capsici*	Percent plants with *M. incognita*	Average knot index[1]	Plant height (cm)	Marketable yield (kg/m^2)
BM 60	0.8 a	11.1 a	0.1 a	159 a	8.2 a
Hybrid 1	2.3 c	89.2 c	2.9 b	133 c	6.3 c
2	0.5 a	70.7 b	2.2 b	147 b	7.1 b
3	1.4 b	61.2 b	2.0 b	150 b	7.0 b
BM 60	0.8 a	0.0 a	0.0 a	136.2a	6.9 a
Hybrid 2	9.4 b	60.0 d	2.2 b	120.7 b	5.9 b
25	0.0 a	10.0 b	0.3 a	127.8 b	6.2 b
26	0.7 a	40.0 c	1.6 b	109.2 c	6.0 b
27	0.0 a	36.8 c	1.0 b	114.0 bc	5.3 c
28	0.5 a	57.9 d	1.3 b	120.0 b	5.8 b
29	1.8 a	12.5 b	0.4 a	107.4 c	6.7 a
30	0.0 a	0.0 a	0.1 a	139.0 a	6.8 a
BM 60	1.3 a	20.0 a	0.6 a	143.2 a	8.9 a
Hybrid 23	0.5 a	83.3 bc	3.3 c	118.3 c	6.3 de
25	2.1 b	100.0 c	5.9 d	122.4 bc	6.7 cd
28	0.0 a	100.0 c	5.3 d	123.8 bc	6.1 de
29	0.0 a	83.3 bc	2.3 b	125.0 bc	7.5 bc
30	3.3 bc	73.3 b	4.1 c	139.8 a	8.2 ab
43	4.3 c	64.3 b	3.6 c	141.1 a	5.5 e
46	0.0 a	100.0 c	5.6 d	144.5 a	6.7 cd
56	0.0 a	60.0 b	0.6 a	128.4 b	6.0 de
57	4.0 c	40.0 a	0.4 a	124.2 bc	8.0 b
58	0.0 a	100.0 c	1.8 ab	125.1 bc	8.3 ab

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. [1]According to Bridge and Page (1980)

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THE CURRENT STATUS OF ALTERNATIVES TO METHYL BROMIDE IN VEGETABLE CROPS IN FRANCE

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ABSTRACT

Vegetable production in France was valued at 2,234 million euros in 2000 and contributes significantly to the agricultural economy. Integrated Pest Managment (IPM) provides growers with a a practical solution for integrating new methods such as soilless systems or grafting to eliminate harmful fumigants without totally omitting chemical options. Methyl bromide (MB) has the highest cost per hectare of all registered agricultural compounds which has acted as a disincentives to its further use in France. The main alternatives are dazomet, dichloropropene, metam sodium, sodium tetrathiocarbonate, solarisation and steam depending on the crop and its locality. The amount of land treated with MB has decreased significantly in the past 3-4 years, particularly in strawberry production where soilless subtrates are now used. To allow better comparison between treatments, a protocol has been suggested for adoption by researchers.

Keywords: dazomet, dichloropropene, metam sodium, sodium tetrathiocarbonate, solarisation, steam, IPM, strawberry, melon, tomato, cucumber

INTRODUCTION

Vegetable crops remain an important economic part of French agriculture. Vegetable production in France was valued at 2,234 million euros (Anon 2000). All of these crops can be described as intensive, their production requiring a high level of grower technical knowledge. Controlling the pressures of soilborne pathogens is still one of the main agronomic aims and soil disinfestation is an available curative measure.

Recently, consumer demand for residue-free products of high quality, the future European registration of pesticides, and considerations of the safety of pesticides to growers are all modifying cultural practices in France. Today, integrated pest managment (IPM) provides growers with a a practical solution for integrating new methods such as soilless systems or grafting to eliminate harmful fumigants without totally omitting chemical options.

METHYL BROMIDE USES

Since 1997, the consumption of methyl bromide (MB) for soil disinfestation has decreased significantly (Table 1) due to three main reasons: International decisions taken by governments under the Montreal Protocol, inorganic residue problems for several vegetable crops which, for example resulted in the banning of the use of MB on lettuce, and because MB has the highest cost (around € 9,000 per ha) compared to all registered compounds. Despite these reasons, MB is still required in the production of tomatoes, strawberries, cucumbers, cut flowers and forest nurseries. MB is the only compound that eradicates specific pathogens like *phomopsis scleroïdes* on cucumbers.

ALTERNATIVES TO METHYL BROMIDE

It is difficult to give a precise view due to the diversity of crops and production areas in France. However, we can see two main tendencies in vegetable crops with two specific markets: the development of chemical fumigants in open fields mainly on carrots or potatoes; and the development of non-chemical alternatives in greenhouses like steam, grafting or soilless systems.

Registered Fumigants - chemical alternatives

Table 1 shows the relative change in use of five chemical compounds, the only ones registered in France as alternatives to MB (Fritsch 2001). The global use of chemical fumigants is increasing, especially 1,3-dichloropropene (1,3-D) and metam sodium. Because of its broad spectrum and easy application (liquid formulation, possibility to inject it into a drip-irrigation system), metam sodium is the potential alternative to MB in several cases, especially on strawberries. It can be used to obtain a herbicide effect, for example on leek seedlings. Dazomet has a very broad spectrum, but is too expensive compared to other chemical fumigants.

Table 1: Trends in use for soil disinfestation techniques in France in 2000.

Soil disinfestation techniques	Treated hectares	Tendency
Dazomet	1,000	stable
Dichloropropene	7,000	up
Metam sodium	4,000	up
Methyl bromide	1,203	down
Sodium tetrathiocarbonate	500	up
Solarization	200	stable
Steam	2,000	stable
Total surfaces	15,903	up

Sodium tetrathiocarbonate (commercial name: Enzone) which can be applied after planting is very effective against *Meloigogynes spp.,* especially on melons. Sometimes, resistant grafted plants can become infested by rootknot nematodes, mainly if there is a large population, and a good harvest can be maintained by using this compound.

Nevertheless, more and more growers are using new means of applying chemical fumigants: low dosages for metam sodium, irrigation pipes for 1,3-D, virtually impermeable sheets for disulfide generators (Sodium tetrathiocarbonate).

Low dosages of fumigants combined with solarization is another method used in the Roussillon region, for example, on lettuces to reduce the risk of residues.

Non-chemical alternatives

Soilless culture is increasing significantly as the replacement for MB use on tomatoes and strawberries, its main use. For both crops, we can also see an improvement in the hanging rain gutter system with organic or inorganic substrates.

The total production area of tomotoes in 2001 was 3,428 ha consisting of 1,293 ha in open fields (soil disinfestation not required) and 2,135ha in greenhouses (Anon 2001). About 950 ha are now planted with soilless systems which is particularly prevalent in the Northeast, Britanny. MB disinfestation still occurs in non-heated greenhouses in the south of France, mainly to eliminate *Pyrenochaeta lycopersici*.

Ten years ago, there were around 500 ha/year of land for strawberry production (excluding nurseries) that was disinfected with MB out of a strawberry production area 1,580 ha. Over a three or four year period, strawberry growers adopted soilless cultivation which reduced the amount fumigated with MB to only 150 ha in 2000. A mixture made of peat and organic substrates (pine bark) or inorganic substrates are used on these 150 ha.

Grafted plants ave also proven useful. The Agronomic Research National Institute’s variety “Brigeor” uses hybrid vigour to give resistance to tomatoes to *Pyrenochaeta lycopersici*, *verticillium*, *fusarium oxysporum f.sp. lycopersici* and *fusarium oxysporum f.sp. radicis* and to nematodes. The “Beaufort” variety predominates because it gives resistance and “Maxi fort” seems to have better resistance against nematodes. Grafted plants are also used on eggplants to decrease susceptibility to *Verticillium dalhiae*, a pest which causes significant damage in the South of France (Lot and Garonne Valley, Vaucluse). Melons are mainly grafted with a hybrid of *Curcurbita maxima* and *C. moschata* (ex: RS 841, P360) against *Fusarium* and *Phomopsis scleroïdes* (Monnet 2001)

RESEARCH PROTOCOL FOR ALTERNATIVES

Field trials must be instigated to find potential alternatives to MB. It would be useful if scientists used a common protocol or methodology to evaluate chemical or non-chemical alternatives.

The suggested approach is to report a correlation between three important parameters in micro-plots, i.e. 1) Quantification of the main active ingredient on pathogens (for example: gas concentrations for fumigants) including a comparison with mortality obtained in the laboratory; 2) Direct biological efficacy using systematic artificial infestations; and 3) Agronomic behaviour of the crop.

A working group of scientists, technicians, contractors and soil fumigant users are currently in the process of creating an official methodology for the "Commission des Essais Biologiques", an official expert committee in France. In the near future, this protocol will be followed for each new registration for soil disinfestation compounds.

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APPENDIX 1

Table 1 : Methyl bromide consumption (tonnes) in 1997 and 2000.

Crops	Consumption 1997	Percentage share	Consumption 2000	Percentage share	Tendency
Tomatoes	410	29.2	141	19.7	-65.1
Strawberries	295	21	150	21	-49.2
Cut flowers	144	10.3	80	11.2	-44.4
Cucumber	125	8.9	100	14	-20
Horticultural nurseries	62	4.4	50	7	-19.4
Melons	56	4	10	1.4	-82.1
Arboricultural.re plant	53	3.8	55	7.7	+3.8
Aromatic plants	42	3	30	4.2	-28.6
Pepper	30	2.1	20	2.8	-33.3
Tobacco seedlings	26	1.9	5	0.7	-80.8
Carrots	25	1.8	2	0.3	-92
Courgettes	25	1.8	2	0.3	-92
Lettuces	24	1.7	2	0.3	-91.7
Substrates	24	1.7	25	3.5	+4.2
Asparagus (nurseries)	21	1.5	2	0.3	-90.5
Forester nurseries	20	1.4	26	3.6	+30
Eggplants	12	0.9	10	1.4	-16.7
Leek seedlings	5	0.4	2	0.3	-60
Vineyards replant	3	0.2	3	0.4	0
Total	1402	100	715	100	-49

BIOLOGICAL CONTROL AGENTS IN VEGETABLE CROPS AS ALTERNATIVES TO METHYL BROMIDE

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ABSTRACT

The effect of time, frequency, and multiple applications of the egg parasitic fungus *Verticillium chlamydosporium* in reducing population densities and crop damage caused by *Meloidogyne javanica* were evaluated in unheated plastic houses in Barcelona, Spain. The effect of the fungus on crop yield was also evaluated. The fungus survived in the soil throughout the growing season and parasitized nematode eggs in all the experimental conditions tested. The fungus consistently decreased plant damage in all experiments except in the post-planting fungal treatment carried out 10 weeks after planting. However, it did not affect final nematode densities or egg production. Accumulated tomato yield in nematode-free plots was always higher (P=0.05) than in nematode-infested plots whether they had been treated with the fungus or not.

Keywords: antagonist, egg parasites, fungus, Meloidogyne, plastic houses, root-knot nematodes.

INTRODUCTION

Root-knot nematodes, *Meloidogyne* spp., are a major pest in vegetable crops worldwide. Currently, nematode control is based mainly on the use of soil fumigants and nematicides. Constraints imposed on the use of nematicides by legislation and consumers are leading to the development of new management strategies including biological control.

Microbial antagonists of nematodes can be exploited as biological control agents (BCA) either alone or in combination with other management strategies. *Verticillium chlamydosporium* is a facultative parasite of nematode eggs that has been extensively investigated as a potential BCA for cyst and root-knot nematodes. The tri-trophic interaction occurring in the soil between the fungus, the plant, and the nematode is complex and several factors affect the performance of the fungus (Kerry 2000).

The objective of this research was to determine the effect of time, frequency, and multiple applications of *V. chlamydosporium* in reducing population densities and crop damage caused by *Meloidogyne javanica* in unheated plastic houses. The effect of the fungus on crop yield was also investigated.

MATERIALS AND METHODS

Procedure. The soils from the experimental sites were infested with *M. javanica*, and located at Centre de Cabrils, IRTA, Cabrils, Barcelona (site Q21), and at Can Comas Farm, Consell Comarcal del Baix Llobregat, El Prat, Barcelona, Spain (site CC). The soil was sandy loam and loam, at sites Q21 and CC, respectively. The experimental design was incomplete randomized blocks with five replicated plots per treatment.

The isolate IACR Vc 10 of *V. chlamydosporium* (provided by B. R. Kerry, IACR-Rothamsted, UK) was used for the experiments. Fungal inoculum was mass-produced on a solid medium consisting of a moist autoclaved mixture of coarse sand and corn flour that was inoculated with the fungus.

After four weeks' incubation at 25ºC, fungal biomass was recovered by washing and sieving. The concentration of chlamydospores in the fungal suspension was estimated in diluted samples using a haemocytometer (de Leij *et al.* 1993). Trials were done in a similar way unless otherwise stated. Nematode-free plots were obtained by methyl bromide fumigation (75 kg/m^2) in October 1998.

Frequency of application. To determine the effect of one or two applications of the fungus, lettuce seedlings cv Arena were planted in October 1999 and harvested after 16 weeks of growth in February 2000. Tomato seedlings cv Durinta were planted on 9 and 14 of March at sites Q21 and CC, and harvested after 17 and 19 weeks of growth respectively, in July 2000. Plots consisted of a single row 3.4 m long with six plants/plot spaced 50 cm in the row. Initial nematode density (Pi) before planting the tomato seedlings was 1,200 nematodes (J2) / 250 cm^3 soil at site Q21, and nematodes were below detectable levels at site CC. The fungus was applied at a rate of 1x10^6 chlamydospores/plant at the time of planting the lettuce seedlings in autumn, and a second application at a rate of 53 x 10^6 and 67 x 10^6 chlamydospores/plant was done at the time of planting the tomato seedlings in spring at sites Q21 and CC, respectively.

Time of fungal application. The effect of pre-planting or post-planting applications of the fungus was tested on the tomato plants. Trials were run in parallel to the previous ones. The pre-planting fungal application rate was 53 x 10^6 and 67 x 10^6 chlamydospores/plant at the time of planting tomato cv Durinta at site Q21 and CC, respectively. The post-planting application rate was 20 x 10^6 chlamydospores /plant. The inoculum was delivered at a volume of 800 ml/plant as a soil drench 10 weeks after planting. Plants were irrigated immediately after inoculation.

Multiple fungal applications. The effect of multiple applications of the fungus during cultivation of tomato plants was determined at site Q21. Plots consisted of two rows (3.4 m long and 1.5 m wide) with twelve plants/plot spaced 50 cm in the row. The Pi was 1190 J2/250cm^3 soil. Tomato seedlings cv Durinta were planted on 12 March, and harvested on 10 July 2001. Individual plants received a total of 122 x 10^6 chlamydospores, which were applied at one-week intervals for 6weeks starting 6 weeks after planting. The fungus was delivered through a drip irrigation system at a volume of 4 l/plot. Plants were irrigated immediately after inoculation.

To determine densities of *M. javanica*, composite soil samples were collected at the beginning and end (P. final) of each experiment. Individual samples consisted of five soil cores taken from the first 30 cm of soil with a soil auger (2.5-cm diameter). Soil cores were mixed thoroughly and nematodes extracted from 500-cm^3 soil subsamples by Baermann trays. The number of nematodes was expressed as J2/ 250 cm^3 soil. Nematode damage was evaluated after the final harvest using a gall index. Following sampling for final densities, four or eight plants/plot were dug and rated for galling on a scale of 0 to 10, where 0 = complete and healthy root system, and 10 = plant and roots are dead.

Eggs were extracted from two 10-gram root subsamples by blender maceration in 0.5% NaOCl solution for 10 minutes. Fungal densities were estimated at the end of the crop in representative 1-gram soil and root subsamples from each plot using dilution plate on a semi-selective medium (de Leij and Kerry 1991). The numbers of colonies of *V. chlamydosporium* (cfu) were counted after three weeks' incubation at 25 ºC. Parasitism of nematode eggs was assessed following the procedure described by de Leij and Kerry (1991). Eggs were considered parasitized if fungal hyphae were growing out of them.

To determine crop yield, fruits produced per four or eight tomato plants/plot were harvested as they matured. Tomatoes were collected once each week for 6 weeks. Fruits were counted and weighed, and the accumulated tomato yield was expressed as kilogram per m^2. For statistical analysis, the nematode-free treatment was excluded from nematode analysis because *M. javanica* was not detected in these plots during the trials. Data on number of nematodes in soil and eggs/g root, and on number of cfu in soil and roots were transformed to [log (x+1)], and subjected to analysis of variance using the GLM procedure of SAS version 8, and analysed by site. Tomato yield data were subjected to analysis of variance. When the overall F test was significant, means were separated by LSD procedure (P =0.05).

RESULTS

Frequency of application. The fungus was re-isolated from parasitized eggs of *M. javanica* in both plastic houses nine (Vc) and four (Vc 2X) months after its application, and was recovered from all inoculated plots at site Q21 but only from two or three plots at site CC (Table 1). Repeated fungal applications (Vc2X) tended to increase percent egg parasitism.

Fungal distribution in soil and root also tended to increase after two fungal applications at site Q21. In contrast, the fungus was not established in the soil of site CC after one application, and was only recovered from root samples after two applications.

Gall rating in fungal treated plots was lower (P=0.05) than in those left untreated at site Q21, but no effect was observed at site CC. The fungus did not affect final nematode densities or egg production.

Accumulated tomato yield was higher (P =0.05) in nematode-free than in nematode-infested plots at both sites regardless of the frequency of fungal applications. There was no difference between fungal treated or untreated plots in plots infested with *M. javanica*.

Table 1: Effect of the frequency of application of *Verticillium chlamidosporium* (Vc) on population densities of *Meloidogyne javanica* (Mj) and yield of tomato cv Durinta in two plastic houses infested with the nematode in Barcelona, Spain.

Site	Frequency application	P. final (J2/250 cc soil)	Gall[1] rating	Eggs/ g root [2]	Parasitized egg (%)	[3]cfu/g soil	cfu/g root	Yield[4] (kg/ m^2)	Fruits (m^2)	Fruit weight (g)
Q21	Vc	14240	6.1 b	53260	3 (5)	100 (2)	200 (3)	8.3 c	89 c	93 c
	Vc 2X	13180	5.8 b	47790	5 (5)	1000 (4)	1000 (2)	10.2 b	102 ab	100 bc
	Untreated	10250	7.0 a	39010	-	-	-	9.7 b	95 bc	102 b
	Mj free	0	0	0	-	-	-	12.2 a	113 a	109 a
CC	Vc	1480	3.4	867	5 (2)	0	0	12.1 b	119	104
	Vc 2X	560	3.2	2190	9 (3)	0	100 (2)	11.5 b	101	120
	Untreated	360	3.2	1330	-	-	-	12.1 b	102	127
	Mj free	0	0	0	-	-	-	13.6 a	110	128

Values are means of five replicated plots per treatment. For each site, means within a column followed by the same letter are not different according to LSD test (P=0.05). In parenthesis, number of plots with the fungus. [1] Based on a scale from 0 (none) to 10 (severe). [2] Parasitized eggs excluded. [3] Number of colonies forming units. [4] Four plants/plot, five plots/treatment.

Time of fungal application. The fungus was re-isolated from nematode eggs when applied in either pre-planting or post-planting tomato at both sites (Table 2).

Parasitism of nematode eggs occurred in all fungal-inoculated plots at site Q21, but they were only recorded from three to four plots at site CC. Tomato plants in pre-planting treated plots showed lower (P=0.05) gall rating than those in post-planting treated or untreated plots at site Q21. The fungus did not affect final nematode densities or egg production at this site. At site CC, final densities of *M. javanica* were higher (P=0.05) in post-planting treated fungal plots than in the remaining treatments.

Accumulated tomato yield was higher (P=0.05) in nematode-free than in nematode-infested plots in both sites, although yield in post-planting treated plots did not differ from that in nematode-free ones (Table 2).

Table 2: Effect of time of application of Verticillium chlamidosporium on population densities of Meloidogyne javanica (Mj) and yield of tomato cv Durinta in two plastic houses infested with the nematode in Barcelona, Spain.

Site	Frequency application	P. final (J2/250 cc soil)	Gall[1] rating	Eggs/ g root [2]	Parasitized egg (%)	[3]cfu/g soil	cfu/g root	Yield[4] (kg/ m^2)	Fruits (m^2)	Fruit weight (g)
Q21	Pre-planting	13180	5.9 b	47100	5 (5)	900 (4) a	1000 (2)	10.2 b	102 ab	100 b
	Post-planting	11800	6.8 a	46420	9 (5)	0 b	50	8.4 c	83 c	100 b
	Untreated	10250	7.0 a	29010	-	-	-	9.7bc	95 b	102 b
	Mj free	0	0	0	-	-	-	12.2 a	110 a	112 a
CC	Pre-planting	560 b	3.2	2190	9 (3)	0	100 (2)	11.5 b	101	120
	Post-planting	2170 a	3.1	150	10 (4)	0	0	13.5 a	102	137
	Untreated	360 b	3.2	1330	-	-	-	12.1 b	102	127
	Mj free	0	0	0	-	-	-	13.6 a	110	128

Values are means of five replicated plots per treatment. For each site, means within a column followed by the same letter are not different according to LSD test (P=0.05). In parenthesis, number of plots with the fungus. [1] Based on a scale from 0 (none) to 10 (severe). [2] Parasitized eggs excluded. [3] Number of colonies forming units. [4] Four plants/plot, five plots/treatment.

Multiple applications. The fungus was re-isolated from eggs of *M. javanica*, and also from rhizosphere soil and tomato roots after six fungal applications at one-week intervals (Table 3). Gall rating in plants from fungal treated plots was lower (P= 0.05) than in those left untreated. The fungus did not affect final nematode densities or egg production. Accumulated tomato yield was higher (P =0.05) in nematode-free than in nematode-infested plots whether they had been treated with the fungus or not.

DISCUSSION

Verticillium chlamydsoporium was successfully introduced in unheated plastic houses in north-eastern Spain. The fungus survived in the soil throughout the growing season and parasitized eggs were recorded from nematode-infected roots at the end of all trials conducted in both plastic houses. These results indicate that the fungus maintained its virulence against *M. javanica*, and was compatible with the agronomic practices and environmental conditions of intensive agriculture in plastic houses. The fungus has a cosmopolitan distribution and has been isolated from eggs of several species of *Meloidogyne* infecting vegetable crops in Spain (Verdejo-Lucas *et al.* 2002). The fungus consistently decreased plant damage in all experiments except in the post-planting fungal treatment applied 10 weeks after planting (Table 2). However, it did not affect nematode densities in soil or root. At site Q21, levels of *M. javanica* at the beginning of each experiment were above the reported damage threshold for *Meloidogyne* (4-5 J2/ cm^3 soil), and densities increased considerably after a single crop.

Table 3: Effect of multiple applications of Verticillium chlamidosporium (Vc) on population densities of M*. javanica* (Mj), and on yield of tomato cv Durinta in a plastic house infested with the nematode in Barcelona, Spain.

Site	P. final (J2/250 cc soil)	Gall[1] rating	Eggs/ g root [2]	Parasitized egg (%)	[3]cfu/g soil	cfu/g root	Yield[4] (kg/ m^2)	Fruits (m^2)	Fruit weight (g)
Vc	10175	6 b	29810	7 (5)	3100 (4)	2150 (4)	9.9 b	90 b	103 b
Untreated	12500	7 a	32830		0	0	9.1 b	92 ab	98 b
Mj free				-	-	-	12.3 a	103 a	118 a

Values are means of five replicated plots per treatment. Means within a column followed by the same letter are not different according to LSD test (P=0.05). In parenthesis, number of plots with the fungus. [1] Based on a scale from 0 (none) to 10 (severe). [2] Parasitized eggs excluded. [3] Number of colonies forming units. [4] Four plants/plot, five plots/treatment.

Percent egg parasitism was low in all experiments, which suggests that effective establishment of the fungus in the field will most probably require several growing seasons because numerous factors affect the saprophytic phase of the fungus, including the receptivity of the soil to the antagonist. Thus, the sandy loam soil of site Q21 appeared more favourable to *M. javanica* and the fungus than the loam soil of site CC since both organisms were more widely distributed and abundant at site Q21 than at site CC.

The time and frequency of fungal applications are important factors that need to be optimized according to local agronomic and environmental conditions to improve fungal performance. Other factors to be considered are application rates and formulation of the fungus.

Because *V. chlamydosporium* is a stage-specific antagonist that only parasitizes nematode eggs, and will not prevent juveniles from entering the roots, the combination of the fungus with other control methods such as resistant plant cultivars, poor nematode host or non-fumigant nematicides would be necessary to achieve nematode control.

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ALTERNATIVES TO METHYL BROMIDE FOR TOMATOES AND VEGETABLES IN ITALY

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ABSTRACT

Italian tomato and vegetable production is economically very important. MB is largely used to control soilborne pests, and to ensure crop productivity and yield stability. The potenial for chemical and non chemical alternatives to replace MB were evaluated. This paper reports the main results obtained by a project supported by EC and Italian Government carried out by five institutions in collaboration during 1998-2001. The key in developing alternatives was soil solarization employed alone or in integrated systems (IPM) with manure (biofumigation), biological antagonists, resistant/tolerant varieties and rootstocks, or by reduced dosages of chemicals. Results showed that, for specific crops and situations, MB alternatives can be accomplished assuring good control and profitable yields. It is furthermore possible to reduce costs, increase quality and provide a safe environment.

Keywords: Soil solarization, integrated pest management, mulching films, soilborne pests, biofumigation, space structural solarization.

INTRODUCTION

The Italian production of tomatoes and vegetables is of considerable economic importance. In intensive agriculture and in the restricted area of protected crops, vegetables are continuously planted in the same field, leading to a rapid buildup of soilborne pests (SPs) attacking the plant's roots. Because of our climatic conditions, many pathogens are known to induce diseases in several major crops causing damage and economic problems. Heavy damage was caused too by nematodes belonging to genera *Meloidogyne*, *Dytilenchus* and *Pratylencus* , as well as by weeds.

To ensure crop productivity and yield stability, it is necessary to treat soil by steam or fumigants to reduce disease damage to below tolerance limit. The high cost of soil disinfestation by steam restricts its use to high-value crops, therefore soil fumigation became the most common approach for SPs control.

Chemicals allowed as preplant soil disinfestation are very few (methyl bromide, metham sodium, 1,3-dichloropropene and dazomet). Methyl bromide (MB) was the predominant choice because of its relatively short treatment period and activity on a broad range of pests.

Unfortunately, this pesticide has been identified as an ozone depleting substance requiring phase out by 2005 except for critical uses. Research was carried out in order to reduce its dosage in agriculture but retain its pathogenic activity. In soil naturally-infested by pathogens and nematodes, it was verified that MB was still active at dosages of 40 and 20 g/m^2 when the soil was covered with virtually impermeable films (VIFs) to conserve gas (Cartia & Minuto 1998).

Studies in Italy that aimed to control diseases affecting tomatoes and vegetables using alternative methods to MB started in 1980 and focused on "soil solarization" (SS) (Garibaldi & Cartia 1991). These studies over the past 20 years in Italy's climatic conditions showed its effectiveness in reducing the population density of many pathogens and nematodes (Table 1).

THE MULTIREGIONAL OPERATING PLAN

Project POM-A12 was carried out to optimize alternatives to MB and to improve soil solarization knowledge and practice. Implemented under the supervision of the Department of Agrochemistry and Agrobiology and financed by the European Community, this project was worked out in a multi-regional context, involving five research institutes and many scientists (pathologists, nemathologists, physicists, engineers) as well as the extension services from Apulia, Calabria and Sicily (Di Primo et al.1999). Nurserymen, fumigation and pest control companies, mulching film manufacturers, builders of machinary applying films on the field, disused film recycling industries and farmers too, were involved. The key in developing the project was SS employed alone or in a integrated system (IPM) with: reduced dosages of chemicals; manure (biofumigation); biological antagonists; resistant/tolerant varieties and rootstocks. The project aimed to reduce costs, increase quality and provide a safe environment.

During a three year period (1998-2001) studies were carried out to verify:

- Thermal regimes in soil subject to solarization (Gutkowski & Terranova 1991);
- The behaviour of innovative mulching films devoted to increase SS effects (Di Primo & Cartia, 1998);
- The activity of biological agents in controlling root rot diseases (Cartia & Causarano 1996);
- The efficacy of SS and IPM methods in controlling soilborne pathogens and nematodes (Cartia et al. 1997).

Biofumigation (BF), combining SS with organic amendments, offers additional option for SPs management involving chemical, physical and biological effects. Amendments were tested such as chicken manure that caused the release of volatile ammonia and an increase of soil temperature resulting in more effect on the resting structure of SPs, followed by solarization alone (Di Primo & Cartia 1998).

Mulching film is an important factor in creating favourable condition for SS treatment and in reducing soil reinfestation. Lately studies on this matter pay particular attention to coextruded plastic film having different photometric properties and color, in comparison with PE mulching film. Green coextruded film (GCF), which inhibits weeds, can be left in place as mulching soil after the solarization reducing pathogens reinfestation in the treated soil (Cascone *et al.,* 2000).

Ethylene tetrafluoroethylene (ETFE) is a greenhouse cover film that improves soil thermal regimes and SS effectiveness (Cascone *et al.* 2001).

Space structural solarization (SSS) is a promising disease management strategy which is a complementary soil disinfestation for the control of inoculum surviving on the structure. In a closed tunnel or greenhouse during July-August, air temperatures were raised to 60-65°C (Di Primo & Cartia 2001a).

Table 1: The main soilborne agents controlled by soil solarization in Italy.

Diseases and pathogens controlled	Host plant	Treatment	References
Basal necrosis	Pepper	Glasshouse	Cartia *et al.* 1987
Ditylenchus dipsaci	Onion Carrot	Field	Lombardi *et al.* 2000 Greco & Cartia 2000
Fusarium oxysporum f.sp. *melonis*	Melon	Tunnel	Di Primo & Cartia 2001
Fusarium oxysporum f.sp. *radicis – lycopersici*	Tomato	Greenhouse	Cartia *et al.* 1997
Globodera rostochiensis	Potato	Field	Greco *et al.* 2000
Meloidogyne incognita	Tomato	Greenhouse	Cartia *et al.* 1997
Meloidogyne spp.	Tomato	Greenhouse	Greco *et al.* 1992; Colombo *et al.* 1992

Diseases and pathogens controlled	Host plant	Treatment	References
	Eggplant Pepper		Cartia 1984; Greco & Cartia 1996
	Lettuce/Melon		Di Vito et al. 1998
Phytophthora capsici	Pepper	Greenhouse	Polizzi *et al.* 1994; Morra *et al.* 1995
Pyrenochaeta lycopersici	Tomato	Greenhouse	Cartia *et al.* 1988; 1989
Pythium ultimum	Cucumber	Greenhouse	Minuto *et al.* 1995
Rhizoctonia solani	Chicory	Greenhouse	Vannacci *et al.* 1997
Sclerotinia spp.	Carrot	Field	Cartia *et al.* 1987;
	Lettuce		Triolo *et al.* 1987; Scannavini *et al.* 1993; Cartia 1996
Sclerotium cepivorum	Onion	Field	Polizzi *et al.* 1995; Di Primo & Cartia, 1998; Agosteo & Cartia 2001
Verticillium dahliae	Eggplant/Tomato	Greenhouse	Tamietti & Garibaldi 1982; Cartia 1984; Cartia *et al.* 1990;
	Eggplant	Tunnel	Tamietti & Valentino 2001

To verify the efficacy of innovative, alternative methods to MB, various experimental trials were carried out in controlling SPs affecting tomato, melon, onion and carrot. The main results are reported.

TOMATO - Fresh market greenhouse-tomato is a major vegetable crop in Italy. Among SPs affecting tomato, *Fusarium oxysporum* f. sp. *radicis-lycopersici* (FORL), *Pyrenochaeta lycopersici* and nematodes (*Meloidogyne* spp.), are the most harmful, inducing Fusarium crown and root rot (FCRR), corky root, and root-knot respectively.

Preliminary studies carried out in the open field showed at 12 days SS reduced survival of FORL propagules significantly. The effectiveness of the pathogen's control was improved by combing SS with manure, or extending the SS treatment to 27 days. In a closed greenhouse, SS and BF with bovine manure proved effective in reducing the viability of FORL chlamidospores, disease incidence, and in increasing commercial yield. Susceptible tomato plants grafted on FCRR-tolerant hybrid rootstock (He-man), even cropped in a severe FORL infested soil, remained healthy during the growing season and gave a profitable yield (Di Primo & Cartia 2001 b).

Trials to test the effectiveness of SS, in comparison with MB, in controlling *P. lycopersici* and nematodes, were performed in greenhouse covering soil with different films. Mulching soil with EVA, GCF, and black coestrused films (BCF), soil temperature exceeded 42.5°C per 373, 265 and 68 hours respectively. Corky root and root-knot symptoms appeared very low in MB and in solarized plot mulched by EVA and GCF treatments, and statistically different from BCF and untreated control (Cascone *et al.* 2000).

The activity of five biological agents in controlling FCRR disease was evaluated on 1700 seedlings grown in nine different greenhouses. Because of the light incidence of FCRR, disease control appeared evident only by "Fus Più", and no yield increase was recorded (Polizzi & Catara 2001).

MELON - *Fusarium oxysporum* f.sp. *melonis* (FOM), the causal agent of muskmelon wilting, causes serious damage to crops grown in unheated tunnels. The efficacy of SS and BF in controlling FOM propagules, placed in the soil at depths of 15 and 30 cm, was tested in an open field and in a tunnel. In the open field, a short solarization period (12 days) induced, in propagules settled at 15 cm, a mortality of 52 and 65% respectively. Combining SS with chicken manure (1 kg/m^2), or extending treatment to 27 days, improved pathogen control. In tunnel trials, chlamidospores were settled at the same depths and soil treated by SS, BF and MB. The SS treatment carried out for 35 days killed propagules placed at 15 cm and induced a mortality of 83% at 30 cm depth. BF and MB treatments obtained 100% mortality at both soil depths. All treatments reduced disease incidence in melon plants and increased yield (Di Primo & Cartia 2001 b).

ONION -The white rot caused by the fungus *Sclerotium cepivorum* is most prevalent on onion crops. Its sclerozia that stay alive for many years is a negative factor in infected soils. In preliminary field trials carried out in Calabria region, SS induced a significant reduction of white rot (89%) and increased the marketable yield (64%) (Polizzi et al. 1995).

SS carried out for 27 days achieved the complete destruction of sclerozia buried at a depth of 15 and 30 cm. BF adding chicken manure into the soil significantly enhanced pathogen control, as early as 12 days after treatment. Sclerozia mortality at the two tested depths reached 100%. The SS of a field amended with organic manure resulted in a better control of sclerozia of *S. cepivorum* and shortened the application time, as compared to either treatment alone (Di Primo & Cartia 1998).

Good results were also obtained using mulching soil with ETFE and GCF. The viability of sclerotia, set in the soil at 20 cm depths, decreased by 26 and 21% respectively, than 10 days of SS and they were completely killed after 20 days (Agosteo & Cartia, 2001).

CARROT -Trials to control *Ditylenchus dipsaci* in carrots were carried out in Sicily to assess the effectiveness of two fenamiphos formulations in combination with SS (August 13 - Septmber 25). The carrots were sown in October. All control plots and only one solarized plot showed many dead or stunted and yellowing plants in early March. Because several generations were developed by nematodes, no significant differences were observed in numbers of nematodes in the soil and in the carrot tap roots at the end of March. However, yield parameters showed highly significant differences. At the end of March the average carrot tap root weight was 58.5g in plots which were only solarized, 62.5 – 77.2 g in plots solarized and treated with fenamiphos and only 30.7 g in control plots. At harvest (17 April), the carrot tap root yield/0.8 m^2 was 3.6 kg in the controls and as high as 8.0 - 9.7 kg in the treated plots, while the average tap root weight was 38.7 g and 92 - 97g, respectively (Greco & Cartia 2000).

CONCLUSIONS

Trials carried out in Apulia, Calabria and Sicily, during a three year period showed that there are, for specific crops and situations, various chemical and non-chemical methods that can control SPs activity and are able to replace MB. In our climatic conditions, during summertime, SS treatment can solve the problems particularly against pathogens sensitive to heat, and its linking with other control methods (IPM) can enlarge activity or extend the control to regions located in Northern Italy.

Research to evaluate and solve the problems related to finding alternatives to MB will need to evaluate what will happen when chemical alternatives to MB increase together with environmental problems.

The project “Toxicological impact of agricultural and energetic activities” is carried out in Sicily to verify which chemicals considered alternatives to MB are used in the Ragusa area in controlling SPs. Preliminary investigations pointed out that 1,3-dichloropropene is largely employed to control soilborne nematodes. It’s use appears promising - chemical residues have yet to be found in treated soil and cropped vegetables.

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ALTERNATIVES TO METHYL BROMIDE FOR TOMATO AND CUCUMBER PRODUCTION IN TURKEY

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ABSTRACT

The effectiveness of an eight weeks solarization period, alone and in combination with other treatments (1,3 dichloropropene, metam-sodium, dazomet, biofumigation, biocontrol-Mycormax , biocontrol-Promot) were compared with the effectiveness of methyl bromide (MB) and control applications. No single alternative can be recommended to replace MB. Solarization, alone or in combination with other treatments such as metam-sodium, 1,3 dichloropropene, dazomet and biofumigation can be recommended in an IPM program to manage soilborne pests in Antalya conditions. Soilless culture treatments also showed promising results in our conditions.

Keywords; Methyl bromide, solarization, biofumigation, biocontrol, dazomet, metam-sodium, dichloropropene, soilless culture, volcanic tuff, peat, tomato and cucumber

INTRODUCTION

Methyl bromide (MB) is one of the most widely used pesticides in the world. It is very effective to control a wide range of pests including pathogens, arthropods and weeds in soil and stores. In Turkey, MB is mostly used in soil fumigation. Total MB consumption in Turkey in 2000 was about 606 tonnes. More than 90% of this amount was used to control nematodes in particular, and also soilborne diseases and weeds in greenhouses in Antalya and Aegean Provinces (Doganay 2000).

Tomato is the main crop grown in greenhouses. Tomatoes account for more than 50% of the vegetable production followed by cucumber, eggplant and some other vegetables produced in Antalya (Anon 2000).

Growers prefer to use MB for better yield. If an alternative to MB is not discovered in the near future in the world, they may not be able to grow these plants because of nematodes and soil borne pests. Although MB is highly effective at controlling soil borne pests, it is destroying the ozone layer and also very toxic human and animals (Bell *et al.* 1996; Katan 1999). Therefore, it is going to be phased out in 2005 in developed countries and in 2008 in Turkey. This situation has stimulated researchers to find alternatives to MB in the world and in Turkey. To find alternatives to MB, a demonstration project was established on tomato (*Lycopersicon esculentum* Mill.) and cucumber (*Cucumis sativus* L.) plants produced under glasshouse conditions in Antalya Province, in collaboration with UNIDO.

MATERIALS AND METHODS

The demonstration project was carried out in Aksu and Kocayatak experiment stations of Citrus and Greenhouse Crops Research Institute in Antalya**.** The trail was conducted following a completely randomized block design with four replicates and approximately 6.5 da. glasshouse. In this project, the tomato variety Fantastic F144 and the cucumber variety Quamar were used as experimental plants. The treatments used in the experiments were solarization (SL), SL+1,3 dichloropropene (DD), SL+metam-sodium (MS), SL+dazomet (DZ), SL+biofumigation (BIO), SL+biocontrol-Mycormax (BCM), SL+biocontrol-Promot (BCP), MB 100% (MB100), MB 50% (MB50) and a control. Other than these treatments, soilless culture treatments [sand (S), volcanic tuff (VT), volcanic tuff+peat(VTP)] were also added to the project just for yield observation.

The surface of the soil in the solarization plots in the glasshouses was covered with 0.02 mm thick transparent polyethylene plastics for 8 weeks during the summer. DD was manually injected into soil to a depth of 15-17 cm using a hand-gun with 6 ml/m^2 dosage. MS (40 ml/ m^2) was mixed manually in tap water pooled into 10 m^2 small plots. DZ granular was spread by hand on the soil surface and incorporated into the soil with a small rotovator at 25 g/m^2 dosage. Fresh chicken manure was used at 5 kg/m^2 as the biofumigation material. Preparations containing *Trichoderma koningii* and *T.harzianum* called Promot (10 gr/L), and *Glomous intraradices* called Mycormax (35-40 gr/L), were used as biocontrol agents. MB plots were covered with polyethylene plastic and MB was applied by drip-irrigation (full dosage 70 g/m^2, half dosage 35 g/m^2).

Microorganisms were counted by diluting them in water. The counts were carried out before solarization and 8 weeks afterwards. Fungi and bacteria in 10 g of soil were counted 10^5 and 10^7 dilution, respectively.

Soil samples (5 samples from each parcel) from the glasshouses were collected to determine nematode (*Meloidogyne* spp.) density. Nematodes (J_2 larval stage) were extracted according to the modified Baermann Funnel method and counted before and after the treatment applications. Root gall indices (RGI) were determined at the end of the vegetation period reported by Zeck (1971): 0=no root system galled; 1=from 1% to 25% of root sytem galled; 2: from 26% to 50%; 3: from 51% to 75%; 4= from 76% to 100% of the root system galled.

Total yield from 21 January 2000 to 27 June 2000 was recorded from each treatment. Tomato and cucumber fruit were classified according to standard marketable sizes as Extra, Class I, Class II for tomatoes; and Extra and Class I for cucumbers.

RESULTS

The weather conditions for 8 weeks from July 26 to September 21 were favourable for all the treatments in the tomato and cucumber plots. The daily mean maximum soil temperatures were recorded for only SL, SL+BIO and the control plots and measured at 10 cm depth in the range of 43-47 °C for SL, 45-52 °C for SL+BIO and 34-46 °C for the control. Soil temperatures at 20 cm depth were in the range of 36-41°C for SL, 38-43°C for SL-BIO and 34-37°C for the control.

The fungal population in tomatoes before treatment was in the range of 29.9-39.2x10^5 in 10 g soil collected from each plot (Table 1). The fungal population for cucumber plots was very similar to that of tomato. All treatments reduced the number of fungi in 10 g of soil in the tomato and cucumber plots, but MB100 was the most effective (Table 1, 2). This was followed by MB50 and SL+MS in tomato. However MB50, SL+DD and SL+MS were effective in cucumber after MB100. At the end of the season, MB100, MB50 and SL+MS were still providing effective fungal control in the tomato and cucumber plots.

The bacterial population in tomato and cucumber plots before treatment was in the range of 50.5-56.2 x 10^7, 51.7-64.6 x 10^7 in 10 g soil, respectively (Table 1, 2). All treatments after application reduced the number of bacteria in all tomato and cucumber plots, but MB100 was the most effective. The effectiveness of MB50, SL+MS and SL+DD was very close to the effectiveness of MB100 in tomato. In cucumber MB50, SL+MS and SL+DD were also effective but not as effective as the MB100 dosage in the tomatoes. At the end of the season, MB100, MB50 and SL+MS still reduced the number of bacteria in 10 g soil in tomato and cucumber plots.

In the tomato and cucumber plots, the number of *Meloidogyne* spp. before the treatments was in the range 255.8 - 321.1 J_2 and 130.0 - 182.5 J_2 in 100 cc soil, respectively (Tables 1, 2). After the applications, all treatments reduced *Meloidogyne* spp. population, but MB100 application was the most effective (3.6, 3.3 J_2) at controlling *Meloidogyne* spp. in tomato and cucumber, respectively. This was followed by MB50, SL+DD and SL-BIO.

The highest infestation (Tables 1, 2) was observed in the control plots which had RGIs of 3.8 on tomato and 2.3 on cucumber. The level of RGI was the lowest in MB100 treatment on both tomato (0.2) and cucumber (0.02). MB50, SL+BIO, SL+DD also had low levels of RGI in tomato and cucumber.

In tomato plots, all treatments increased the marketable yield compared to the control (Table 1). The greatest yield was obtained in SL+BIO plots (20597.5 kg/da). This was followed by SL+DD, SL+DZ, MB100 and MB50 treatments. In cucumber, all treatments except SL+BCM increased the marketable yield compared to the control (Table 2). The MB50 treatment provided the greatest yield (9249.2 kg/da). The yield of MB100, SL+DD, and SL+MS treatments was also higher than that of control.

Among soilless culture treatments, sand provided the highest yield (21064.1 kg/da) in tomato. The yield using VTP (20436.2 kg/da), VT (19420.4 kg/da), MB100 (19163.1 kg/da) and MB50 (19138.9 kg/da) were very close to each other, but significantly higher than that of control (14940.9 kg/da). In cucumber plots, all the soilless culture and MB treatments provided higher yield than that of the control. The highest yield was obtained from MB50 plots (9249.2 kg/da). This was followed by VTP (8501.7 kg/da), MB100 (8066.7kg/da), VT (7829.7kg/da) and S (7763.6 kg/da).

DISCUSSION

Solarization has been reported as an alternative to MB alone or in combination with other chemicals (DD, MS, DZ), biofumigation and biocontrol agents (Di Vito *et al.* 2000; Gamliel *et al.* 2000; Minuto *et al.* 2000; Tamietti & Valentino 2000). In our experiments, solarization may also be an effective alternative method to MB either alone or in combination with other methods. SL is very suitable and applicable for use in the Antalya province due to the favourable environmental conditions. Antalya has very strong sunlight for approximately 250 days in a year and the summer (July and August) is very hot. During July and August (total 55.5 days completely sunny and clear weather) the glasshouses are empty. This situation makes solarization possible in Antalya conditions.

MB100 was the most effective treatment to reduce number of fungi and bacteria in soil in both the tomato and cucumber plots. SL+MS, SL+DD, SL+DZ and SL also significantly reduced fungal and bacterial populations and the effectiveness of these treatments was close to the MB applications in the tomato and cucumber plots. Therefore, SL+MS, SL+DD, SL+DZ and SL may be alternatives to MB, but SL+MS may be the most favorable alternative for controlling fungi and bacteria. Similar results have also been reported by Reuven *et al.* (2000) for MS, Gamliel *et al.* (2000) for SL+MS and Minuto *et al.* (2000) for SL+DZ.

The results of this experiment indicated that MB100 was the most effective treatment to reduce the number of nematodes in both the tomato and cucumber plots. SL+DD and SL+BIO were also effective for controlling *Meloidogyne* spp., in fact close to the effect of the MB treatments. Therefore, these treatments may be recommended to control *Meloidogyne* spp. in tomato in Antalya province. However, SL+BIO containing a very high level of nitrogen (especially chicken manure) may not be recommended to control *Meloidogyne* spp. in cucumber as the plants are made very susceptible to soil borne diseases. The RGI was below 1 in the SL+DD and SL+BIO plots treated in tomato and cucumber at the end of the vegetation period. Similar results for SL+DD were reported by Di Vito & Campanelli (2000).

In the treated tomato plots, all the treatments increased the marketable yield compared to the yield of the control (Table 1). The greatest yield was obtained in SL+BIO plots (20597.5 kg/da). This resulted from chicken manure which contained high level of plant nutrition materials and microbial activity.

In conclusion, no single alternative can be recommended to replace MB. Therefore, an IPM programme must be considered to manage soil borne pests in Antalya conditions. However, solarization alone or in combination with other treatments (SL+MS, SL+DD, SL+DZ and SL+BIO) may be recommended as alternatives to MB to control soilborne pests. Soilless culture treatments also showed promising results in our conditions.

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Table 1: Effects of different treatments on the incidence of fungi, bacteria and nematodes, and on the yield in **tomato**.

Treatments	**Fungi (10 gr/10^5)**			**Bacteria (10 gr/10^7)**			***Meloidogyne* spp. (J_2/100 cc soil)**			**Root-Gall Index**	**Total Yield**
	Before Treatments	After Treatments	At Harvest	Before Treatments	After Treatments	At Harvest	Before Treatments	After Treatments	At Harvest		
Control	39.2 a*	41.0 a	41.0 a	56.2 c	58.8 a	59.0 a	321.1 a	266.0 a	520.0 a	3.8 a	14940.9 d
Solarization	36.3 a	13.8 de	21.0 c	58.6 ab	16.4 d	21.3 cd	224.0 b	35.0 c	70.0 bc	1.5 b	17356.5 c
Solarization + Dichloroproene	38.6 a	13.0 de	20.6 c	62.4 a	9.5 e	16.4 d	284.0 ab	11.5 fg	40.0 de	0.8 bcde	19566.8 ab
Solarization + Metam sodium	31.2 a	11.7 e	19.5 c	55.6 c	8.5 e	16.5 d	290.3 a	30.3 cd	70.5 bc	1.14 bc	18157.4 bc
Solarization + Dazomet	29.9 a	16.4 de	21.0 c	54.6 c	20.9 cd	21.9 cd	255.8 ab	22.8 de	56.0 cd	1.06 bcd	19521.3 ab
Solarization + Bio fumigation	32.8 a	18.8 d	20.1 c	50.5 c	26.7 c	27.9 c	292.5 ab	18.5 ef	48.5 d	0.3 de	20597.5 a
Solarization + Bio control (m)	37.2 a	33.4 b	34.0 b	62.9 a	52.8 ab	53.2 ab	308.5 a	48.8 b	85.5 b	1.6 b	18006.7 bc
Solarization + Bio control (p)	35.3 a	25.3 c	25.9 c	57.8 c	49.3 b	51.5 b	260.0 ab	46.8 b	78.5 b	1.5 b	18636.7 bc
Methyl Bromid 100%	34.2 a	1.2 f	3.2 d	57.9 c	0.0 f	4.2 e	273.3 ab	3.5 g	8.5 f	0.2 e	19163.1 ab
Methyl Bromid 50%	34.0 a	2.5 f	6.4 d	56.5 c	2.0 f	8.5 e	276.0 ab	11.0 fg	30.0 e	0.4 cde	19138.9 ab

*:Treatments with the same letters are not significantly different according to Duncan Multiple Range Test, P=0.05

Table 2: Effects of different treatments on the incidence of fungi, bacteria and nematodes, and on the yield in **cucumber**.

Treatments	**Fungi (10 gr/10[5])**			**Bacteria (10 gr/10[7])**			***Meloidogyne* spp. (J_2/100 cc soil)**			**Root-Gall Index**	**Total Yield**
	Before Treatments	After Treatments	At Harvest	Before Treatments	After Treatments	At Harvest	Before Treatments	After Treatments	At Harvest		
Control	38.1 a*	38.4 a	39.1 a	61.8 a	57.4 a	60.7 a	177.0 a	130.0 a	375.0 a	2.3 a	6474.1 c
Solarization	35.7 a	14.9 c	20.9 d	53.1 a	17.9 cd	21.9 d	130.0 a	19.0 bc	58.5 bcd	1.4 b	7242.1 bc
Solarization + Dichloroproene	34.7 a	14.0 c	19.5 d	64.6 a	14.6 d	18.7 d	182.5 a	10.8 cd	20.0 gh	0.8 d	7874.3 ab
Solarization + Metam sodium	38.9 a	14.2 c	18.7 d	51.7 a	14.1 d	18.4 d	150.3 a	14.8 c	50.0 cde	1.2 bc	7844.9 ab
Solarization + Dazomet	36.4 a	15.6 c	20.1 d	55.6 a	16.2 d	20.3 d	155.0 a	13.3 cd	42.0 def	1.0 cd	6841.7 bc
Solarization + Bio fumigation	34.8 a	26.1 b	28.2 c	60.3 a	22.0 c	30.1 c	171.0 a	12.5 cd	40.0 ef	0.8 d	7646.5 abc
Solarization + Bio control (m)	33.3 a	24.5 b	33.6 b	55.4 a	50.2 b	55.7 b	166.0 a	25.3 b	60.5 bc	1.4 b	6337.0 c
Solarization + Bio control (p)	38.2 a	19.7 c	29.6 bc	57.1 a	48.3 b	52.3 b	147.0 a	26.5 b	68.5 b	1.5 b	6718.0 c
Methyl Bromid 100%	38.0 a	0.9 d	2.7 e	58.6 a	0.7 e	4.8 e	175.3 a	3.3 d	5.0 h	0.02 e	8066.7 ab
Methyl Bromid 50%	37.1 a	1.8 d	5.8 e	56.1 a	2.9 e	9.0 e	181.5 a	11.8 cd	26.0 fg	0.08 e	9249.2 a

*:Treatments with the same letters are not significantly different according to Duncan Multiple Range Test, P=0.05

ALTERNATIVES TO METHYL BROMIDE FOR SOIL TREATMENTS IN CUBA

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ABSTRACT

Methyl bromide (MB) has been used for soil treatments to control pests in Cuba since 1969. About 400 tonnes were used on a range of crops during the 1980's but in 1998 only 80 tonnes were consumed due to the development of alternatives and a national drive toward integrated pest management programmes. These programmes include control of weeds by disrupting seed development or desication of those weeds with vegetative organs, rotation crops, solarization, varieties of crops resistant to nematodes, biological control programmes for nematodes, limited chemical intervention, and the use of organic substrates. MB is no longer used in tobacco production due to the introduction of the floating tray technology. Grafted plants and bio-fumigation are under evaluation for use on protected crops such as tomato, pepper, water melon and cucumber. Steam has been used with success in seedbeds of tobacco but complicated procedures as well as high fuel costs make this alternative unattractive in Cuba.

Keywords: methyl bromide**,** alternatives, soil preparation, rotation crops, solarization, biological control, resistant varieties, IPM.

INTRODUCTION

Cuba has an agricultural economy whose development can be divided in four fundamental phases. The first prior to 1959 was characterized by a monoculture of sugar cane, the second after 1959 when there was a radical transformation starting from the laws of agrarian reform, the third was based on the recovery of fertile lands and the production was intensified, diversified and specialized, with increased yields due to chemicals and mechanization. Today, the last stage started in 1993 with qualitative and quantitative transformations that allowed conditions to be created for technological reconversion to low inputs, careful use of resources, use of biotechnological products, and with more emphasis on sustainability and preservation of the environment.

Of the cultivated land, except for the sugar cane and pasture, rice represents 25%; citrus 21%; vegetables, grains and tubers 17%; coffee and cocoa 13%; other fruit trees 9%; and tobacco 3%. In the last 10 years, an important increase has taken place in the production of vegetables, especially those grown under protected crop cultivation and in urban agriculture. The largest increases have been in cut-flower and ornamental plant production.

Methyl bromide (MB) has been used for soil treatments to control pests in Cuba since 1969. At the moment, it is used in tobacco seedbeds, protected cultivation of tomato, pepper, watermelon, cucumber, flowers and ornamental plants and substrate for coffee nursery. Large quantities of MB were used in 1980-81 when annual consumption was 400 tonnes; and during the decade of the 1980's. In 1990, 133 tonnes were used due to a programme of remarkable reduction in the use of this MB. In 1998 only 80 tonnes were consumed.

The introduction of the protected crops between 1990 and 1995 was associated with the use of MB to eliminate nematodes, soil borne disease and weeds in tomato, pepper, water melon, cucumber and other crops that have a current demand of 20 tonnes. Two tonnes were used in cut-flowers and ornamental plants. One tonne was used coffee nursery plantations. Despite increased areas dedicated to these protected crops in the last few years, the consumption of MB has not increased in the same proportion as alternatives have been sought to replace MB that would be viable under an integrated pest management programme.

The Government of Cuba endeavours to implement its commitments to the Montreal Protocol, some of them financed by the Protocol through implementing agencies like UNIDO in the project of "Phasing Out Methyl bromide in the Tobacco Sector in Cuba." In addition, Cuba has established a system of licenses for import and export of ozone depleting substances which guarantees freezing the quantities and ensures successive elimination of these substances.

The main species of pests present in the soil that justify the use of MB in different crops include: the fungi *Phytophthora spp, Rhizoctonia solani* Kuhn, *Phythium spp*. and *Fusarium spp*; the nematodes *Meloidogyne incognita* (Kodoif and White) Chitwood and *M. arenaria*; mites of the genus *Rhizoglyphus;* and weeds *Cyperus rotundus* L., *C. esculentus* L*., Amaranthus dubius* Mart*, Parthenium hysterophorus* L., *Echinochloa colonum* L., *Eleusine indicates* L., *Rottboellia cochinchinensis* (Lour) Clayton and *Sorghum halepense* (L) Pers.

ALTERNATIVES TO METHYL BROMIDE

Soil preparation

Weeds that reproduce via seeds with a high viability can be controlled manually with great effort immediately before the flowering period and rain season. This is carried out with different kinds of implements. On the other hand, those that reproduce by vegetative organs (rhizomes, stolons, tubers, basal bulbs) require tiller and multiplow to bring to the surface the self generating organs during the dry period in order to desicate them. With 3-4 tiller passes at the end of the preparation this species decrease substantially.

The time between the manual effort to kill the weeds that reproduce by seeds is linked to the conditions existing for their germination in which rain plays a main role. Under normal conditions during the rainy period, 12-15 days between efforts are required. Those weeds that reproduce vegetatively, once the rest of the plants have risen to the surface of the soil, the time to wait depends on the susceptibility of these organs to desiccation and loss of viability. For example, *C. rotundus* requires 7-9 days, and *S. halepense* requires 8-10 days (Pérez *et al.* 1999).

Since the radical systems of several plants or their underground organs continue to live and serve as host to the nematodes, mites and fungi for weeks or months after the crop, and the fact that several species of these parasites have a high survival even without a host, it is necessary to expose these parasites to the sun to contribute to their gradual mortality. In Cuba, *Meloidogyne spp*. was largely eliminated using a disk plow to invert the soil prism in combination with tiller every 25 days for 60-90 days (Fernández 1999).

Rotation crops

Rotation crops have a big influence in the composition and population of weeds. In Cuba, the intercropping (spring crops) affect notably the incidence of annual and perennial gramineous, *C. rotundus* and *Amaranthus spp* as this proliferate in the most favorable conditions of humidity and temperature. As an exception, *P. hysterophorus L.* is distributed by the effects of the main crops. In general, variable rotations lead to the best results because they do not allow the conditions that contribute to the population growth of certain species of plants to occur repeatedly (Pérez *et al.*1990).

Some systems of rotations have been included as part of an integrated pest management programme for weeds in Cuba. To control *R. cochinchinensis* and *S. halepense,* begin with sweet potato as permanent or variable intercropping and follow this by leguminous plants such as soy and velvet bean. More than two leguminous crops reduces the incidence of these weeds, but yield is reduced. To eliminate *C. rotundus,* fallow periods with intercropping of sweet potato and corn is used.

The benefit of the potential allelopathic properties of the crops can be shown by sowing corn at 45x25 cm spacing and incorporating fresh mass to the soil so that it reaches 50-60 cm of height with a production of vegetable mass of 6.4 kg/m^2. This reduces the populations of *R. cochinchinensis*, *C. rotundus* and *S. halepense* (Labrada 1990). Equally, by sowing and incorporating *Stizolobium deeringianum Bort, the* weeds are eliminated and in the next tobacco crop the use of herbicides decrease by 20%. Intercropping of *Sorghum vulgare* Pers reduces the incidence of *C. rotundus* (Fernández *et al.* 1990). In general, the leguminous *Canabalia ensiformis (L)* and *S. deeringianum* were important species in a rotation system because of their associated production of toxins.

Succession in horticultural crops is recommended according to their susceptibility to *Meloidogyne spp*. It is known that there are very susceptible crops such as tomato, eggplant, lettuce and water melon; moderately susceptible crops such as cabbage and cauliflower; and lightly susceptible crops such as garlic and onion. Similarly, crops such as peanut, sesame, corn or the resistant variety of sweet potato CEMSA 78-354 can precede susceptible crops. Good results have been obtained in the elimination of *Meloidogyne* in tobacco with the rotation of peanut, millet, velvet bean, corn and sesame (Fernández *et al.* 1990).

The use of rotation crops for 3 consecutive years is effective for reducing the incidence of *P. nicotianae var. nicotianae* in tobacco.

Solarization

Solarization in Cuba requires about 45-60 days in periods of high temperature and sunshine that occur in July and August. As solarisation is expensive and complicated to use, it is recommended for the control of nematodes, soil born disease and weeds in seedbeds (Fernández *et al.* 1990). Good results were achieved using solarization to control *Meloidogyne*, several weeds and *P. nicotianae, R. solani* in traditional tobacco seedbed, protected crops, urban agriculture and hydroponics with located watering (Fernández 1999). To obtain the best results with solarization, it is necessary to ensure the soil is fluffy before covering, that an appropriate hermetic seal over the soil is achieved, that sufficient time is allowed, that it is carried out in the appropriate season and that infestations after solarization are avoided.

Resistant varieties

The use of resistant or tolerant varieties is economic and environmentally sure method. Today, there are some commercial varieties of tomato, tobacco and pepper that are resistant to *M. incognita* (Sasser 1989; Montes *et al.* 1998). Nevertheless, these varieties should be managed carefully, because the continuous sowing in the same area can select species or races that are in the minority initially but they can converted by resistance so that they dominate. Such a case was reported in tobacco in South Carolina where the indiscriminate sowing of varieties like "Speight G-28" controlled *M. incognita* race 1, but there emerged with force race 2 as well as *M. arenaria* (Fortum *et al.* 1994). This situation also occurred in Cuba, but the new dominant species is *M. javanica* for which a resistance source does not exist in the genus *Nicotiana* (Fernández 1999).

Recently, the varieties of tobacco "Habana-92", "Habana-2000" and "Corojo especial" have been introduced that are less affected by ***P. nicotianae,*** compared with the traditional varieties " Criollo" and "Pelo de Oro."

BIOLOGICAL CONTROL

*Trichoderma spp***.**

Recently in Cuba, some research has been undertaken to evaluate the use of species of the genus *Trichoderma* for biological control of *P. nicotianae; P. capsici; Pythium aphanidermatum; Sclerotium. rolfsii* and *Fusarium spp.* Their application to the soil and substrate in a preventive treatment in seedbeds or different stages crops reduces the appearance of soil borne disease caused by fungus in tobacco, pepper and tomato. *Trichoderma* could be produced by handmade methods on solid supports or in static liquid media using by-products of the sugar industry as raw materials. So much the biomass of the fungi formed for conidia, clamidospora and mycelia as the metabolites, they exercise an effective control against the sensitive pathogens. Of the *T. harzianum* strains isolated, the most promising for the control of *P. nicotianae* are "A-53" and "A-84" which give good control of the disease under field conditions (Stefanova & Sandoval 1995)

Among the benefits noted that contribute to the treatment with *Trichoderma spp* has been the stimulant effect on plant growth in different crops.

Micorriza-arbuscular

Several experiments have been carried out with the objective of knowing the interactions that settle down in the soil between the fungus formed of Micorriza-arbuscular and different pathogens of plants. The effectiveness of the micorrizas as inhibitors of the action of these noxious organisms has been demonstrated.

Experiments carried out in Cuba showed that tobacco plants treated with micorriza are less affected by *P. nicotianae.* The level of reduction of the disease compared with non treated plants depended on the strain used. *Glomus mosseae* (strain "Habana") was the most effective in the reducing the disease (80%), while other strain decreased infection between 20 and 50%, compared to 100% of plants infected without treatment. The interactions of micorriza-host-pathogen depend on the environmental conditions and the soil type. This is being taken into account in future research programmes, particularly for control of *P. nicotianae* in tobacco cultivated in sandy soil.

Paecilomyces lilacinus

P. lilacinus is a fungus which parasitises the eggs and adults of several species of a nematode phyto-parasite. It also produces toxins. Both effects are manifested in acid soil. Good results have been reported for the control of tropical nematodes *Meloidogyne spp* and *Radopholus similis* in diverse countries using products that are made locally or produced commercially. This fungus in Cuba has been produced locally and has produced good results in field conditions for control of *Meloidogyne spp* and *Radopholus similis* through preventive application to *in-vitro* banana and coffee plants that are inoculated in nurseries and then planted (Fernández 1999).

Bacillus thuringiensis

A native strain of *Bt.*, effective for controlling field populations of *R. similiis* and *P. coffeae,* is under evaluation (Fernández 1999).

CHEMICAL PRODUCTS

The use of pesticides to control most soil pests is the easiest and most effective method. However, the current tendency is toward a decrease in pesticide use. Cuba has evaluated many chemical pesticides as alternative to MB, among these currently registered for use in different cultivations are: Aldicarb, carbofuran and fenamifos for nematodes; azoxystrobina, benalaxylo + mancozeb, captan, metalaxyl, propamocarb hydrochloro against fungi of the soil, mainly *P. nicotianae;* napropamida, napropamida + metribuzin, oxadiazon, oxifluorfen, glyphosate for weeds; and dazomet as soil sterilizer.

ORGANIC SUBSTRATES

Cuba has achieved good control of *Meloidogyne* with the phlegm of sugar cane semi-composted and applied into the holes of transplanted perennial plants. Incorporation into the soil of cruciferous crops like cabbage after it has been broken into fragments and lightly fermented was reported to reduce substantially nematode populations due to the formation of toxic compounds such as ammonia and several sulphurous compounds.

INTEGRATED PEST MANAGEMENT IN CUBA

Research has been carried out with the objective of having different alternatives for the management of pests, diseases and weeds in different crops. One of the basic aspects constitutes the development of quick methods for the diagnosis and prognosis of the main species of pests and evaluation of scales established as damage thresholds. Success has been achieved in the selection of areas for IPM, the use of practical agronomic techniques, the use of chemical alternatives, and the use of biological control against insects, disease and nematodes.

An example of these results is the use of IPM and floating tray technology in traditional tobacco seedbeds where crop rotation is limited. Cuba has developed an unique solution consisting of organic substrate composed of black pit or compost of sugar cane phlegm (80%) + husk of rice (20%), mixed with *T.harzianum* to 1kg/ha in two times. In general, biological control is given priority for pest control. This technology provides healthy plants of standard size with a vigorous and protected root system. This technology requires rigorous control of quality during the production process that includes periodic monitoring of the main noxious organisms that can prosper in the humid atmosphere and under conditions of sterilized substrate, and that can prosper in the transmission of any infection when the leaves are pruned. The introduction of this technology has totally eliminated MB in tobacco cultivation in Cuba.

OTHER METHODS

Grafted plants and bio-fumigation are under evaluation for use on protected crops such as tomato, pepper, water melon and cucumber. Steam has been used with success in seedbeds of tobacco but complicated procedures as well as high fuel costs make this alternative unattractive in Cuba.

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BIOFUMIGATION AS AN ALTERNATIVE TO METHYL BROMIDE

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ABSTRACT

Biofumigation is based on the management of the bio-decomposition process of organic matter, which produces volatile substances that, by being kept in the soil, are able to regulate the population of plant parasitic organisms. Results confirm that biofumigation is as effective as conventional pesticides in the control of fungi, nematodes, insects and weeds. The practice of biofumigation increases the biodiversity of edaphic fauna, also improving physical and chemical soil properties. The main limiting factor to biofumigation is the cost of transporting biofumigants; therefore, it is important to use local resources. Biofumigation is shown to increase its efficacy over time, since harmonic systems of production are planned, based on the management of biological and environmental diversity.

Keywords: nematodes, organic matter, soil ecology, crop protection, agroecology.

INTRODUCTION

New paths of research have been opened up in crop protection, stemming from the action of organic matter, which produces gases in the process of its decomposition, that can effect the control of plant pathogenic organisms since they work as fumigants. This process is defined as biofumigation and was included as a non-chemical alternative to methyl bromide (MB) by the Montreal Protocol's Methyl Bromide Technical Committee (MBTOC 1997).

Our research has permitted biofumigation to be defined as: "the action of volatile substances produced during the bio-decomposition of organic matter for plant pathogen control." Biofumigation increases its effectiveness over time when it forms a part of an integrated production system. It has been found that generally any organic remains could act as a biofumigant, their efficacy depending on their characteristics, dose and method of application. Excellent examples of the application of biofumigation exist in vegetables, strawberry, pepper, tomato, citrus fruit, banana, grape and cut-flowers in Spain. The most utilized biofumigants are goat, sheep and cow manure, and crop remains from rice, mushroom, olive, brasica and ornamental gardens. It has been demonstrated to be just as effective as conventional pesticides in controlling nematodes, fungus, insects, bacteria, and weeds, and can regulate problems with viruses by controlling vector organisms (Bello *et al*. 2000).

This paper describes the methodology for applying biofumigation in the field in a form as accessible to technicians as farmers. The section on results evaluates first of all the efficacy of nematode control by various biofumigants from animal sources, green manure and agro-industrial remains. Lastly a synthesis is made of the principal results obtained. Three representative cases are selected that correspond to the use of biofumigation in vegetable crops at El Perelló (Sueca, Valencia), pepper crops in Murcia and tomato and melon in Uruguay.

METHODS

The methods of application of biofumigation were described by Bello *et al.* (2000), which indicated that it was an easy technique for farmers and technicians to apply, since it only differs from organic matter amendments in the choice of the biofumigant, which should be partly decomposed, and in the method of application. This method must take into account the necessity of retaining for at least two weeks the biofumigant gases produced from the bio-decomposition of organic matter, since their effect in the majority of cases is not biocide but rather biostatic. Therefore it is necessary to prolong the time of their action on the pathogens. It has been demonstrated that any agro-industrial remains, or combination thereof with a C/N relation between 8-20, can have a biofumigant effect. The use of a dose of 50 t/ha (tonnes per hectare) is recommended, although when problems with nematodes or fungus are very serious, the dose should be increased to 100 t/ha, which can be reduced through crop techniques such as application in furrows. The biofumigant should be uniformly spread so that focuses of pathogens do not appear in the future, which could create problems for the crop. Once the biofumigant is spread, it should be incorporated immediately into the soil, tilled once with a rotovator, and watered preferably by spraying until the soil is completely saturated.

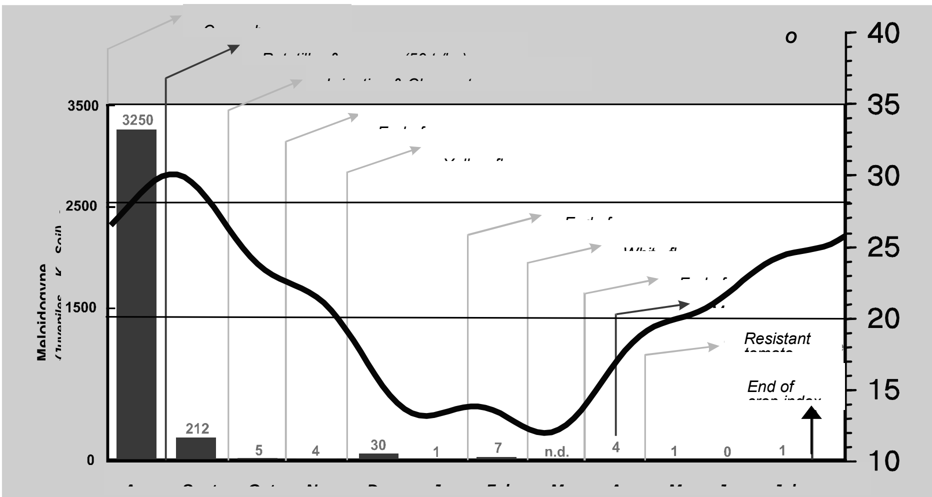
RESULTS AND DISCUSION

The great majority of the biofumigants selected were found to have an efficacy of 100% in the control of *Meloidogyne incognita*, with root knot indexes in Marmande cv. tomato plants, sensitive to this nematode, that did not exceed a value of 3.8 according to Bridge and Page's (1980) scale of 1 to 10. Values of efficacy under 100%, as well as higher indexes, are a consequence of possible errors in application or the absence of an activating substance. On the other hand, an increase in saprophagous nematodes was generally observed.

In relation to the effect of biofumigation on the height of Marmande cv. tomato plants cultivated on treated soils, values have generally been higher or, in some cases, similar to the control group. Biofumigation can also have a benevolent effect on the physical properties of the soil, particularly in respect to its compactness. In relation to the chemical properties of the soil, a general increase is observed in the majority of the parameters determined, with the exception of Ca, which presents a tendency to decrease, as well as Na, to a lesser degree. In some treatments with brasica, rice hull, sugar cane husks, wet olive pomace, and wheat straw, a drop in nitrogen content and organic matter may appear which shows up as decrease in the biomass of the Marmande cv. tomato plant grown on soils biofumigated with these materials. Therefore, it would be necessary to establish fertilization programs that would take into account the characteristics of the biofumigant and the soil where it is applied.

The cost of biofumigation is very low when local resources are used, as in the case of green manure or agro-industrial remains. Treatments with animal manure can be more expensive, especially due to transportation, although the cost can be reduced by means of the use of agricultural techniques that lower the dose of application. It must also be taken into consideration that in many crops the use of organic matter is a normal practice, differing from biofumigation only in the characteristics of the organic matter as well as the dose and method of application.

Biofumigation in vegetables at El Perelló (Valencia, Spain) (Bello *et al.* 1996) (Figure 1).

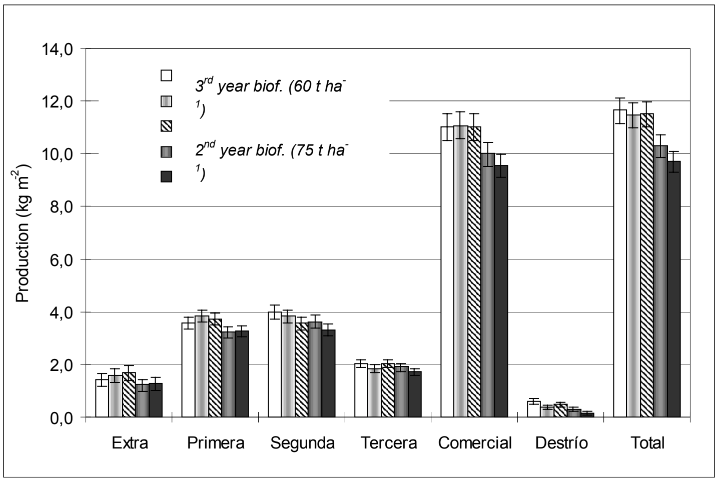


Biofumigation was carried out using a mixture of sheep manure and mushroom remains at a dose of 50 t/ha and applied in the month of August. This was followed by cultivation for about two months of trap plants consisting of short-cycle Chinese vegetables as they disrupt the biological cycle of the *M. incognita* nematode, the principal phytopathological problem in the area. The population reduction avoids the possible development of virulent populations which could appear after using tomato resistant varieties with *Mi* gen, helping in that way to reduce the total number of nematodes at the end of the tomato crop. This permitted the cultivation of sensitive plants in the second year such as cucumber or melon.

Figure 1. Biofumigation and integrated production in vegetables at El Perelló (Valencia, Spain) (Bello *et al*. 1996).

Biofumigation in pepper crops at Murcia, Spain (Bello *et al.* 2001a) (Figure 2). A mixture of sheep and chicken manure was used which was applied with solarization at a dose of 100 t/ha, during the month of August, in a greenhouse affected by *M. incognita*, strain 1, at Campo de Cartagena (Murcia). The results of continued biofumigation treatments for one, two and three years were analyzed, compared with the control group and with the MB treatments. Biofumigation provided a similar level of effectiveness as MB in the control of *M. incognita* and weeds. Some difficulty could appear in the first biofumigation treatments, but with time, the farmer may become familiar with the method and select mixtures of biofumigants and establish the most effective doses.

Figure 2. Average production by quality classes in 2000-01 campaign. LSD Intervals to 95% with Log $_{10}$(x+1) transformed data (Bello *et al.* 2001).



Biofumigation in tomato and melon crops in Uruguay. Biofumigation consisted of the application of various types of organic matter such as chicken manure plus rice hull, sheep manure, cow manure, chicken manure, crop remains, agro-industrial remains and compost (De León *et al.* 2000, 2001). These treatments were complemented with other crop practices such as crop rotation, the use of vegetable coverings and tolerant cultivars or those sensitive to *Meloidogyne*. The results obtained showed that the proposed management systems had a high efficacy in the control of *M. arenaria* and *M. incognita*. The positive effects of biofumigation on physical and chemical soil parameters were outstanding. Through the design of these alternative horticultural systems, the decrease and even elimination of the use of agrochemicals are achievable as well as a reduction in production costs (Table 1, see next page).

CONCLUSIONS

The effectiveness of biofumigation is similar to that of conventional pesticides, but at the same time, biofumigation improves soil and plant characteristics. When using biofumigation, it will be necessary to design crop production methodology for each situation. The efficacy of biofumigation is increased with time when it forms a part of an integrated production system.

The cost of biofumigation can be inexpensive, especially when animal manures, green manure or agricultural remains are used. It is actually an organic amendment and the differences are principally in the characteristics of the organic matter, the dose and the method of application. The use of local resources as biofumigants is recommended as one of the principal costs of transport can be reduced. Problems with soil fertilization and plant nutrition can arise, such as a deficit in nitrogen, but they can all be solved with adequate fertilization.

Table 1: Cost in US dollars of production using biofumigation in tomato and melon crops in Uruguay[1].

CROP / CRITERIA	PRODUCTIVE SYSTEM	
	CONVENTIONAL	BIOFUMIGATED
TOMATO [1]:		
Variety	Facundo (sensible)	Tommy RN (resistant)
Length of crop (Months)	6	5.5
Total (kg)	8,700	7,910
Kg per plant	4.7	4.7
kg m^{-2}	12.2	11.5
Production costs	486	376
Gross income	**2,583**	**2,707**
MELON [2]:		
Variety	Galia	Galia
Length of crop (Months)	5	5
Total (kg)	758	444.2
Kg per plant	438	484.8
kg m^{-2}	8,550	9,150
Production costs	1,618.9	1,351.9
Gross income	**3,505.5**	**3,751.5**

[1] Labour is not included; [2] Average cost on 15 farms in a conventional system

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ALTERNATIVES TO METHYL BROMIDE FOR TOMATO PRODUCTION IN BELGIUM

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ABSTRACT

Belgium has 40 years of soil disinfestation experience with the use of methyl bromide (MB) and its alternatives that have been used for growing tomatoes in soil and for intensive production of vegetables. Belgium's use of MB declined in 2001 to 102 tonnes, approximately one-third of the amount consumed in 1991, due to adoption of substrates such as rockwool, grower fear of exceeding bromide residues in MB-fumigated crops, exclusion of MB from crops grown organically and a decline in intensive agricultural land. At present, alternatives to MB are important not so much because of the restrictions on future use imposed by the Montreal Protocol but because there are several new methods under development with which Belgium already has experience including integrated soil inoculation, 'partial substrate culture', 'bio-fertilisers' and 'microbiological soil analyses'. This paper discusses these developments and other concepts that together make up the building blocks for the future success of horticulture.

Keywords: biofertiliser, biopesticide, biosoil amendment, coconut fibre substrate, ecological boomerang, integrated soil fumigation, microbiological soil analysis, partial substrate, partial laying-fallow, soil inoculation, virtually impermeable film

INTRODUCTION

Belgium is a country with a rapidly evolving horticulture. Within the intensive vegetable sector, tomatoes are financially the most important crop. Approximately 75 to 80% of the tomatoes are produced on rockwool substrate without the need for disinfestation. The remaining tomato production is, just like the production of lettuce and several other vegetables, soil-bound and still requires soil disinfestation. Statistics on soil fumigation in Belgium will therefore always relate to the intensive, soil-bound vegetable sector.

For about four decades, horticultural soils have been fumigated in Belgium with a battery of physical and chemical soil sterilization methods. Soils for intensive vegetable cultivation under glass or outdoors used to be almost exclusively chemically disinfested, and this mainly carried out by registered soil fumigators. Approximately 40% of these chemical soil sterilizations were done with MB, the remainder with chloropicrin, dichloropropene (1,3-D) and metam-sodium.

The state of affairs in 2001 looked completely different as chemical alternatives to MB have gained the upper hand. Could this be attributed to the restrictions imposed by the Montreal Protocol? Which MB alternatives or alternative combinations show great promise for the Belgian grower?

SOIL FUMIGATION IN BELGIUM

For over 40 years, soil disinfestations have been carried out in Belgium in order to eliminate accumulated microbiological soil sickness. This is the result of a insufficient crop rotation and an intensive monoculture. Approximately 20% of the intensive vegetable cultivation is sterilized by growers themselves using steam or dazomet. The remaining 80% is disinfested by registered soil fumigators who use strong chemical fumigants like MB and chloropicrin, as well as the weaker alternatives like 1,3-D and metam-sodium. The use of steam as a viable alternative remains relatively unimportant because of the hard labour required, the big energy consumption and the high price.

In Belgium MB has been continuously decreasing in significance and its consumption in 2000 was about one-third of the amount consumed in 1991. Estimated amounts in 2001 show consumption to have declined still further to about 10% of 1991 levels (Table 1).

Table 1: Reduced use of MB (tonnes) in Belgium[1]

1991[2]	1992	1993	1994	1995[2]	1996	1997	1998[3]	1999	2000	2001[3]
312.09	267.32	289.28	201.46	221.12	186.667	180.21	127.46	145.60	102.17	33.00[4]

[1] Mr. Houins - Belgian Ministry of Agriculture - [2] Reference Years (Montreal Protocol); [3] Obligatory reductions: 25% in '98 and 50% in '01 (Montreal Protocol) – [4] Estimated value.

What are the reasons for this remarkable decline in the use of MB? First of all the great attraction of the substrate culture. Indeed, 75 to 80% of the tomatoes and as much as 100% of the cucumbers and sweet peppers are now grown on substrates. Only lettuce remains 100% soil-cultivated. The precise management of crops on a thin substrate layer, the urge to implement innovations and the initially interest in 'premium prices' have made a lot of growers switch over from soil to substrate culture. This automatically resulted in a large decrease of MB for soil fumigation and implied that the introduction of a MB ceiling of 25% in 1998 and 50% in 2001 imposed by the Montreal Protocol, compared to the 1991 base level, did not pose a problem for Belgium.

So we can safely say that substrate culture is a very important MB alternative for tomatoes in Belgium, although this growing method also has to contend with typical 'substrate born pests and diseases'. These problems can be avoided by replacing the old substrate or by vacuum steaming the substrate slabs in special containers. Growing in these kinds of artificial and watery substrate slabs is not only expensive but it also entails controlling new and/or obstinate diseases and pests which often necessitates an increased use of chemicals.

A second important motive for adopting alternatives to MB is the fear of exceeding bromide residues in harvested vegetables. The enforced maximum residue levels in Belgium of 30 ppm bromide for tomatoes and 50 ppm for lettuce are being controlled more rigorously than ever and more often than in any other country. A grower that exceeds the permitted level must destroy the crop that is in non-compliance.

A third reason for the considerable increase in the use of MB alternatives is growers' uncertainty over the extent of the Belgian government's liability (dated 22 July 2000) for a crop that exceeds the maximum permitted residue level and that may not control pests and diseases adequately when a mandatory, half-dose of MB (4.5 kg/100m²) is applied under virtually impermeable film (VIF). However, grower scepticism appears to be unfounded as the soil pest and diseases are being controlled and the bromide residue norms are not being exceeded due to additional aeration and leaching measures. One could expect that increasing grower confidence in MB with VIF will increase the use of MB to more than 50 tonnes again!

Certain growers with a classic crop rotation system under glass of 'summer tomatoes - autumn lettuce - spring lettuce', have withdrawn themselves from the obligations for the use of MB under VIF by using the 'partial substrate culture' system. They still grow soil-bound lettuce, but they cover the soil up with plastic during the summer, on which they grow summer tomatoes in buckets filled with coir (coconut fibre substrate). In comparison with rock wool, coir substrate is cheaper and better naturally recyclable. Very little is known about the prevention and controlling of 'coir born pests and diseases' in this organic medium. The soil is in every way temporarily unused, therefore this technique could also be labelled as 'partial laying-fallow'.

A fourth reason for reduced MB consumption is possibly due to the exclusion of MB in the cultivation guidelines for 'Organic Food' and 'Organic Farming'.

Finally, the area of the intensive horticulture and consequently also the number of soil fumigations with MB, have been decreasing slightly over the past 10 years in Belgium.

Table 2 shows that in 5 years time the share of MB alternatives for soil fumigation, has been increasing considerably. In 1996 still 50% of the area of intensive outdoor vegetable growing and the cultivation under glass was being disinfested with strong fumigants of which 45% were with MB. The remaining 50% was being disinfected with weaker MB alternatives, of which 45% was 1,3-D. In 2001, the situation has turned over completely: 75% of weaker soil disinfectants of which 65% are 1,3-D, and 30% of strong soil fumigants of which 25% is MB.

Table 2: Use of chemical alternatives (%) to MB that became more important in Belgium[1]

			Percent in 1996	Percent in 2001
MB-ALTERNATIVES TOTAL:			55	75
	Strong:	Chloropicrin	5	5
	Weak:	Dichloropropene	45	65
		Metham-sodium	5	5
MB-TOTAL			45	25

[1] SEGO (Special Registered Soil Fumigators Belgium) and De Ceuster Soil Ennoblement (Belgium)

METHYL BROMIDE ALTERNATIVES

What are the experiences with these chemical MB alternatives in Belgium? First of all, they have a smaller and/or weaker action spectrum, as is shown in Table 3. They are therefore less effective for growers, especially with a very intensive monoculture e.g. all the year round lettuce growing 6-7 crops per year, and/or with less favourable growth circumstances and thus with greater disease and pest pressure.

Table 3: Action spectrum of chemical soil disinfestants[1]

	FUNGICIDE (F)	NEMATOCIDE (N)	INSECTICIDE (I)	HERBICIDE (H)
Methylbromide	FFFFF	NNNNN	IIIII	**HHHHH**
Chloropicrin	**FFFF**	**N**	**IIIII**	**HH**
Dichloropropene	**FFF**	**NNNN**	**IIII**	**HHH**
Metham-sodium	FFF	**N**	IIII	HH

[1] Actual and practical appreciation scheme for chemical soil disinfestants by SEGO (Special Registered Soil Fumigators Belgium) and De Ceuster Soil Ennoblement (Belgium)

Furthermore the weaker chemical alternatives for MB, like chloropicrin, 1,3-D and metam-sodium have several significant disadvantages. At present the concern is whether or not these alternatives have a direct, negative impact on man and environment. Because of their limited action spectrum, it is very likely that in the future growers will be applying more pesticides during cultivation. The residue cocktail of these cultural crop protection agents is unpredictable and in all respects harder to trace than the bromide residues in soil and crops. What is more, the repeated and single use of weak chemical soil disinfection alternatives can lead to uncontrollable, cumulative, soil sickness and/or biological adaptation of the soil. Such biological aberrations and/or complete ineffectiveness of the soil disinfestation agents have an ecological boomerang effect on the grower.

When selecting new disinfestation alternatives or alternative combinations, Belgian growers and soil fumigators are always guided by at least 3 parameters: the efficient action spectrum, the absence of harmful residues in harvested vegetables and the safety for the workers and the environment.

Which MB alternatives or alternative combinations show real promise for the Belgian grower in the future? Whether or not the substrate culture will become an even more important alternative for soil-bound vegetable growing and thus for MB soil disinfestations depends entirely on the consumer. Because debates on quality, taste and storage life of substrate vegetables, as well as about the increased use of pesticides in artificial substrates, will continue.

A new, beautiful, organically-based variation on the substrate culture, namely the 'partial coir substrate' or the 'partial laying-fallow system', offers promise providing sufficient microbiological diversity can be maintained in the rhizosphere.

Grafted plants and disease- and pest-resistant varieties are partial alternatives for MB. However, their protection spectrum is often very limited and in addition plant pathogens regularly break through their resistance. Besides disease and pest pressure differs from year to year.

As a matter of fact, an ideal and reliable substitute for the simple but extremely efficient molecule of MB has yet to be discovered. Many of the available alternatives still have to prove their worth in time and space. Until then MB can - as half a dose applied in a low-emission manner under VIF - be appointed the useful role of 'correction tool'. Particularly for those cases of diagnosed soil sickness, which can not be controlled anymore by means of classic chemical or physical substitutes. A good follow-up of the bromide residue danger is still highly recommendable. It's a sad paradox that the same worldwide efforts are not made to develop workable and valid MB alternatives as the efforts that have already been made to simply ban MB. Perhaps a better application of chemical alternatives to MB can open up new opportunities for pest and disease control. Probably the action spectrum of weaker soil fumigants can be improved by applying them under VIF.

The additional inoculation of microbiological preparations (antagonists) with chemical disinfestation, so called integrated soil disinfestation, results in increased efficacy e.g., against *Pyrenochaete* or 'corky root' with tomatoes. Integrated soil disinfestation will definitely reduce pesticide use and even provide a certain after-protection. It would be a welcome prospect to know that better control of resistant forms that are hard to destroy like sclerotes of *Sclerotinia*, chlamydospores of *Fusarium* or pseudosclerotes of *Rhizoctonia* could be obtained. Provided that the soil is inoculated regularly, the frequency of the soil fumigations can be reduced. Over the last 17 years, Belgium has gained a wealth of practical experience and know-how concerning integrated soil fumigation. When using chemical MB alternatives frequently and monotonously, it is imperative to avoid biological adaptation. This is achievable with the aid of an early detection technique. In this context, Belgium has already developed an adaptation test for metam-sodium. It is also very useful to alternate chemical soil fumigants and/or to diversify microbiologically the disinfested soil with microbial preparations.

Nonetheless, horticulture in Belgium will, despite the limited available quantity for 'critical use', have to miss the comfort and the efficiency of soil fumigations with MB from 2005 onwards. Growers and soil fumigators will have to be extremely attentive to assessment and application errors. It will become of crucial importance to make the correct and ultra-early disease and pest diagnoses by means of a microbiological soil analysis, because it is only there and then that the (weak) biological inoculations stand a chance. These kinds of analyses give us an idea of the microbiological diversity in the rhizosphere and a 'forecast' of any imbalance. This technique draws a picture of the degree of infestation in the soil, of biological buffering and of the biological protection thanks to the natural presence of antagonists. The analyses will advise us on whether soil fumigation, soil inoculation or the combination of both are required. Belgium already has 7 years of experience in pest and disease monitoring.

Growers often cultivate in a biological vacuum, as is the case with recently fumigated soils or new potting soils. This is fundamentally wrong since pest and disease incidence can originate from organisms that remain viable but resistant after treatment, or they may immigrate from external sources to more easily occupy open 'niches' than the slower but useful antagonists.

Consequently 'Good Horticultural Practice' obliges growers to avoid incidences of a biological vacuum in the rhizosphere by means of induction and imitation of beneficial crop rotation effects. In fact, more is needed as such potential infection sources (irrigation water, composts, substrates) must be microbiologically "dammed up" and even armed with suppressive 'bio-fertilisers'. It is better to start a new crop with a positive predominance in the rhizosphere than with a biological balance.

Microbiological preparations are often conveniently, and without all too much microbiological insight, classified as 'bio-pesticides' which results in all the unpleasant obligations of expensive and time-consuming registrations. It would be much more correct and justified to apply them – more preventively than preventive – as 'bio-fertilisers' or as 'bio-soil amendments'. In this context, the opponents of MB could support the horticultural industry by putting in place more favourable approval and legislative procedures to allow more widespread use of these natural, non-genetically modified, microbiological preparations. This may be possible under the terms of a fertiliser legislation, for example.

Finally, it should be pointed out that a healthy tomato and vegetable production in Belgium or elsewhere can only be made possible by the creation of an oxygenous rhizosphere, which stimulates the roots and increases the self-defence capacity of plants. The aerobic 'beneficials' in the soil also benefit extensively from this. Also a strong, intrinsic plant growth based on a mineral-rich, slow-release nutrition which does not stress the plants but nourishes them in a well-balanced and holistic way, can be highly recommended. The rules of good horticultural practice will have to be thought over, rewritten and complied with again, and this applies to Belgium as well.

CONCLUSIONS

Alternatives for MB in Belgium have become more important than MB itself. The switch from soil to substrate culture has made soil fumigations redundant in the cultivation of tomatoes and several other vegetables. In the soil-bound vegetable culture the grower can rely on many years of experience with chemical alternatives of which the shortcomings and possibilities are well-known and which could be applied and combined even more efficiently. Belgium has acquired a wealth of experience with innovations, like microbiological soil analyses, integrated soil fumigation, soil inoculation and suppressive substrates. Belgian growers and soil fumigators are asking to keep MB at their disposal as a 'correction tool', as long as no worthy and affordable substitute has been found. Besides there's still a great demand for recognition and a favourable validation of 'bio-fertilisers' or 'bio-soil amendments'. This would enable a symbiotic cooperation between growers and ecologists, while the truth about MB and the ozone layer still remains hazy!

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ALTERNATIVES TO METHYL BROMIDE FOR USE IN CUT-FLOWER PRODUCTION

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ABSTRACT

Colombia flower exports were valued at about US$650 million in 2001 which made Colombia the world's second largest exporter. Growers initially considered methyl bromide (MB) as an option but soon abandoned its use because MB was too difficult and dangerous to apply, too costly and the soils rich in organic matter fixed bromine causing plant phytotoxicity. Depending on circumstances related to environmental conditions, supplies, available infrastructure and other factors, a number of MB alternatives are being used around the world to grow flowers including steam, solarization, biocontrol, substrates, organic amendments, crop rotation, resistant varieties, biofumigation, metam-sodium, 1,3-dichloropropene, dazomet and chloropicrin. The best results require integration of these alternatives. The paper highlights the advantages and disadvantages of steam, compost, soilless cultivation and fumigants for cut flower production.

Keywords: flowers, methyl bromide, steam, compost, soilless, fumigants, Colombia

INTRODUCTION

Commercial floriculture worldwide is characterized by high investment and stringent quality demands which often imply high pesticide usage. Consumers want perfect flowers – completely free of damage caused by pests and diseases. Additionally, more and more flowers are being grown in tropical countries where the climate is benign and allows for year round production at reasonable costs. The flowers are then exported to temperate countries. Increasing trade in flowers has lead to the establishment of stringent phytosanitary measures at ports of entry in an effort made by importing authorities to avoid accidental entry and spread of unwanted pests and diseases in their countries. Generally, this means that exporters are required to send flowers that are disease and pest free.

Most importantly though, in every country in the world where flowers are grown for commercial purposes, production is greatly affected by severe diseases that prevail and build up in the soil leading to significant losses in yield and quality. Eradicating these noxious organisms from the soil can be difficult; they may even render whole areas unsuitable for the production of susceptible flowers, and make soil disinfestation mandatory. Traditionally, the treatment of choice has been fumigation with methyl bromide (MB) given its wide spectrum of action, its efficacy, and its cost which is usually lower than that of other fumigants.

Upon learning about the MB phase out, many flower growers around the world have expressed deep concern, arguing that there exist no truly efficient alternatives to this fumigant and that, given the strict quality demands imposed on their products, they will go out of business.

However, producing flowers of excellent quality without MB is clearly possible and is already being done. The best example is Colombia, where initial trials with MB failed, forcing growers to look for alternatives thirty years ago. For many years, Colombia has been the second largest flower exporter in the world after Holland. Colombia's export production in 2001 was valued at around US$650 million. Pioneer growers initially considered MB as an option, but abandoned the idea, firstly because it seemed too difficult and dangerous to apply, but also because at the time it was a costly product. Furthermore, the most valid reason for not using MB was due to the very high organic matter content in Colombian soils (18% is common). The bromine from the MB was fixed in the soil leading to phytotoxicity problems that are difficult to solve.

ALTERNATIVES TO METHYL BROMIDE FOR COMMERCIAL FLORICULTURE

Substituting MB requires a grower to take a new approach towards producing flowers. There is no single replacement for this product; rather, a whole programme, involving different measures which together lead to disease reduction, is the answer. In different parts of the world, several alternatives to MB are already in use in cut flower production, often with excellent results. Depending on circumstances related to environmental conditions, supplies, infrastructure available and others, one or another of these alternatives might be more suited for a particular grower. However, the best option is to combine or integrate them in a programme so that together, they lead to the best results.

Table 1: Examples of alternatives to methyl bromide used in cut flower production around the world (Pizano, 2001)[1]

Production type	Alternative	Countries
Protected	Steam	Brazil, Colombia, Europe, USA
	Solarization	Developed countries, Jordan, Lebanon, Morocco
	Biocontrol	Developed countries
	Substrates	Brazil, Canada, Europe, Morocco, Tanzania, US, Colombia
	Organic Amendments	Universal
	Crop rotation	Universal
	Resistant varieties	Universal
	Biofumigation	Developed countries (Spain)
	Metam Sodium	Developed countries, Jordan, Lebanon, Morocco, Colombia
	1,3 Dichloropropene	Developed countries, Colombia
Open field	Dazomet, metam sodium	Developed countries, Brazil, Costa Rica, Egypt, Jordan, Lebanon, Morocco, Tunisia
	1,3 Dichloropropene	Developed countries
	Chloropicrin	Developed countries, Zimbabwe
	Organic amendments	Universal
	Crop rotation	Universal
	Resistant varieties	Universal
	Solarization	Developed countries

[1] Adapted from: MBTOC 1998: Methyl Bromide Technical Options Committee (MBTOC) 1998 Assessment of Alternatives to Methyl Bromide

Among these, the following alternatives deserve further comment, particularly in developing countries where a large part of commercial floriculture takes place today:

Steam sterilization (Pasteurization)

Pasteurization or steam sterilization of the soil is a process by which pests, diseases and weeds present in the soil at a given time are killed by heat. Although dry heat can in theory be applied with very similar results, steam is preferred because it diffuses more efficiently through the soil and is generally more cost effective. In very simple terms, steam sterilization involves injecting or otherwise diffusing hot water vapour into the soil with the aid of a boiler and conductors such as metal or hose pipes in order to kill noxious soil-borne organisms. The soil needs to be covered with canvas or a resistant plastic sheet to keep the steam in contact with it. As a general rule, it is recommended to carry out treatment so that the coldest spot in the soil or substrate is held at 90°C for ½ hr.

If carried out properly, steam is probably the best alternative to MB, proving equally effective. Its utilization is not new to the industry; steam has been used in greenhouses for many decades. In fact, with the advent of soil fumigants, some growers abandoned this technique in their favour, due mainly to reduced costs and simplicity of application.

Many variables influence the success and cost effectiveness of steam, for example the boiler and diffusers used, soil type and structure and soil preparation (Morey 2001; Pizano 2001). Other problems may also arise in association with steaming itself, such as accumulation of soluble salts (particularly manganese), ammonium toxicity and recontamination. Some helpful guidelines to prevent this are: Use only disease-free plant material; Replant treated areas as quickly as possible, ideally as soon as the soil cools off; Avoid disrupting or manipulating the soil whenever possible; and Practice hygienic measures that help prevent disease dissemination. Adding compost and / or beneficial organisms such as *Trichoderma* also gives good results (Carulla 2001).

It is important to note that steam is always more effective when a limited amount of substrate is treated but not the ground soil. This is due to the depth at which harmful organisms can be found in the soil, which too often is either out of the reach of steam or can be reached only at extremely high costs. Heating the soil at depths of more than 30 cm requires much longer use of the boiler, more hand labour and fuel quantities that may render this to costly. However, steam can be used as an alternative to MB for flowers grown commercially, when it is part of an integrated management system that helps maintain diseases and pests at low levels of incidence. This allows for treatment of the first 30 cm of soil to be sufficient for reducing pathogen populations significantly. For example, the carnation wilt fungus *Fusarium oxysporum* f.sp. *dianthi*) can be controlled at costs comparable to those of fumigants (Table 2). Resistant varieties work well with steam, as they can be grown in areas where disease has occurred in the past (Carulla 2001).

Steam has other benefits when compared to fumigants, as these usually require a waiting period – sometimes at least thirty days - before replanting can occur, while steamed soils can be replanted immediately. This sole fact adds one whole month of flower production to steamed areas, representing nearly 135,000 exportable carnation flowers and about $10,000 dollars per hectare (Carulla 2001).

Compost

Originally implemented as a solution to large amounts of plant waste generated in flower farms, composting has now become more popular because the rich organic amendment obtained not only is an excellent fertilizer but also contains high amounts of beneficial organisms that prevent and help control soil-borne diseases. Compost contributes to restoring natural soil flora and increases water retention capacity.

Compost enriched with beneficial organisms such as *Trichoderma* provides very good control of soil fungi such as *Phoma* and *Pythium,* in *Dendranthema* ranges (Valcárcel 2001). These fungi are associated with monoculture, poor soil structure and aeration and deficient water management. Addition of compost has virtually eliminated these problems and no soil steaming or fumigation is now necessary, which represents not only big savings but also a much friendlier approach towards the environment. Costs of the compost programme, including spot treatment with fungicides (applied to disease foci as a drench) have been estimated at $4950/Ha (Rodríguez & Martínez 1996).

Growers also report fewer problems with soluble salts and an overall improvement in plant vigor and productivity. In *Dendranthema* nurseries, compost is easily incorporated into the soil as cropping cycles are short (about four months) and plants have to be completely removed and new ones put in. However, it can also be applied during the cropping cycle of many flowers with excellent results (Pizano 2001).

Soilless substrates

Cultivation of cut flowers on raised beds and in artificial (inert) or soilless substrates (sometimes called hydroponic production) has been widely used for many years in several countries including Holland and Israel. The reasons for using them have generally been associated with the presence of poor soils that are not suited for flower or vegetable production.

Raised or otherwise isolated beds have several advantages including no necessity to fumigate or the possibility of a limited amount of substrate requiring sterilization. Better control of plant nutrition is also possible. In the past, growers in the developing world often considered this option too costly and “high-tech”. Materials such as rockwool and even peat moss were often not available and needed to be imported. Concrete raised beds and floors are usually very expensive. These factors, together with the availability of plentiful extensions of fertile, rich soils, explain why soilless culture did not become widespread in tropical and subtropical countries where flowers are produced. For many years, when soilborne diseases that were difficult to control caused economic losses, a grower would simply plant the next crop on “new” soil, leaving the infested areas for producing a different non-susceptible species.

However, in recent years this situation has started to change. Many times flower industries have developed around large cities where international airports are readily accessible for shipping their products. As cities have developed over time, land often becomes expensive and expansion of farms is restricted, hence new soil is no longer within easy reach. Broad-spectrum fumigants either will not be available (for example MB) or will be restricted in their use by other environmental or health concerns. Steam is too costly as a control measure for soils already containing high populations of pathogens.

These reasons have stimulated flower growers to look for materials and systems that are locally available, suitable for soilless production and economically feasible. Among these, rice hulls, coir (coconut fibre substrate), sand and composted bark, are possibly the most promising (Calderón 2001). Although setting up a soilless production system is expensive – around 47% more expensive than traditional ground beds - growers are able to compensate the extra cost through significantly better yields (20-25%) that result from higher planting density, optimum plant nutrition and better pest and disease control (Carulla 2001; Valderrama & La Rota 2001)

Fumigants

Trials and experiences with soil fumigants in floriculture have shown that their effectiveness varies with factors according to the pathogens to be controlled, the soil characteristics and crop species. These chemicals have been combined together or with other options such as steam with variable results (Arbeláez 2000).

Several fumigants are being evaluated as alternatives to MB, both by commercial growers in many countries, as well as in several demonstration projects conducted by the Montreal Protocol’s implementing agencies (Pizano 2001). The most promising results have been obtained with metam sodium, dazomet and 1,3 dichloropropene + chloropicrin.

Table 2 below presents costs of different treatments in Colombia. However, when determining the treatment of choice, cost is not the only factor to be considered as the environment, sustainability of production, health hazards and others also play an important role in this decision.

Table 2: Comparison of general costs for sterilizing the soil with several fumigants and steam in Colombia[1] (Carulla, 2001; Rodríguez & Martínez, 1996; Trujillo, 2001)

TREATMENT	US DOLLARS PER HECTARE[2]
Dazomet	$5,680
Metam Sodium	$5,120
Dichloropropene[3]	$8,695
Methyl Bromide	$5,030
Steam[4]	$8,479

[1] Figures in US dollars. [2] Includes general hand labor costs. [3] Usually in combination with chloropicrin. [4] Low disease incidence, in combination with integrated pest management.

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ALTERNATIVES TO METHYL BROMIDE FOR CUT-FLOWER PRODUCTION IN SOUTHERN SPAIN

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ABSTRACT

Evaluation of different physical, chemical and biological treatments of greenhouse plots naturally infested with *Fusarium oxysporum* f.sp. *dianthi* was achieved in two consecutive 2-year experiments planted with carnation cvs. Exotica and Master in July 1998 and July 2000, respectively. Steam treatment, and fumigation with Dichloropropene + Chloropicrin failed in Experiment 1 but they were very successful in Experiment 2, indicating their possible use as alternatives to MB. On the contrary, results of metham-sodium fumigation in Experiment 1 were very promising, but its application with injectors in Experiment 2 only produced satisfactory results a few months after planting, which was also the case using poultry manure amendment followed by plastic mulching for 4 weeks. The use of low dose of MB combined with VIF plastic tarping was almost ineffective in Experiment 1 but, when the dose was increased from 20 to 30 g/m^2 in Experiment 2, there was good disease control. The success of the treatments seemed to depend a great deal on the method of application. The combination of eradicative treatments with some degree of resistance in the carnation cultivars is highly recommended.

Key words: soil fumigation, soil solarization, soil steaming, biofumigation, inoculum density, disease progress curves, eradication

INTRODUCTION

Fusarium wilt (FW), caused by *Fusarium oxysporum* f.sp. *dianthi* (Fod), is one of the most important phytopathological constraints of carnation worldwide. Its importance in SW Spain, the largest area of carnation production in Europe, prompted the present work aimed at evaluating different physical, chemical and biological alternatives for reducing pathogen populations including FW to low levels in order to maintain profitable carnation yields.

Soil depth and temperature, as well as methods of application, determine the effectiveness of the chemical desinfestation of soil (Cebolla *et al.* 1984). A low density of pathogen propagules remain usually viable after chemical fumigation, mainly in deeper soil layers where the effectiveness of the treatment is reduced. Therefore, the complete control of Fod is not achieved (Ben-Yephet *et al.* 1994). Incomplete control frequently occurs when physical methods of desinfestation such as steam and soil solarization are applied mainly because the temperatures reached in the deep layers is not sufficiently high to kill them (Elena and Tjamos 1997).

FW has been commonly controlled by means of methyl bromide (MB) fumigation of the soil before planting, but due to its action in depleting the ozone layer, MB is being phased out. Its use will be reduced to 25% of 1991 levels in 2003 and prohibited in the European Community in 2005. Consequently, there is a need to search for alternative treatments than can control the disease. Until these are found, the standard dose of 100 g/m^2 has been reduced to 30 g/m^2, but complemented with the use of virtually impermeable films (VIF) which avoid its immediate release of MB to the atmosphere; otherwise high doses of application would be required.

Alternative methods to MB for disease control were evaluated in two different 2-year experiments conducted in 1998-2000 (Experiment 1) and 2000-2001 (Experiment 2) in a greenhouse naturally infested with the pathogen. Besides an untreated control, treatments with reduced dose of MB+VIF, metam-sodium, and Dichloropropene (1,3-D) + Chloropicrin applications, and soil steaming were tested in both experiments. Standard application of MB was also tested in Experiment 1, whereas the incorporation of poultry manure into the soil, followed by plastic tarping, was tested only in Experiment 2 (Table 1).

Table 1: Soil treatments applied in infested greenhouse previous to carnation planting

Experiment 1(1998/2000)	Experiment 2 (2000/2002)
Untreated control	Untreated control
MB (100 g/m^2)+ PE	MB (30 g/m^2)+ VIF
MB (20 g/m^2)+ VIF	Metham-Na (100 g/m^2)+ VIF Solarization
Dichloropropene + Chloropicrin (40 g/m^2)+PE	Solarization with CP-129 film
Steam (2 h)	Dichloropropene + Chloropicrin (40 ml/m^2)+ VIF Solarization
Metham-Na+Dichloropropene (80+40 ml/m^2) + PE	Steam (2.5 h)
Metham-Na + Aldicarb (80 ml + 10 g/m^2)+PE	Poultry manure (5 kg/m^2)+ CP-129 Solarization

PHYSICAL TREATMENTS

Since the usual dates of carnation planting in SW Spain are late spring to early summer, soil solarization does not seem to be feasible. Therefore, eradication of *F. oxysporum* f.sp. *dianthi* by soil heating was attempted by means of soil steaming. When this technique was applied to plots in Experiment 1, soil assays indicated very low levels of the pathogen in soil samples up to 30 cm depth. Disease symptoms began to show up ca. 3 months after planting cv. Erika, and DI increased with time up to 20% 5 months later and up to 80% 17 months after planting. In comparison, treatments in Experiment 2 seemed to be more effective, confirming complete loss of pathogen viability up to 30 cm depth, and disease onset occurred 4 months after planting carnation cv. Master, although disease progressed at a very low rate, reaching DI<16% at 17 months after planting.

Improvement in the method of soil steam application in Experiment 2 could account for the best disease control achieved. In addition, the use of a less susceptible cultivar could have also contributed to the results obtained.

CHEMICAL TREATMENTS

Several possibilities were tested in experiments 1 and 2. In the first one, MB was applied at 100 g/m^2 and subsequent tarping with transparent PE (standard treatment) and a reduced dose (20 g/m^2) was tested in combination with VIF plastic. Since the only MB treatment permitted now is MB at 30 g/m^2 followed by VIF plastic tarping, this was the reference treatment applied in 2000 (Experiment 2). The satisfactory results obtained in Experiment 1 with the standard application of MB contrasted with the poor results obtained with the reduced dose of MB+VIF. The latter treatment reduced DI to ca. 60% by the end of the experiment, as compared to the reduction to 20% achieved by the standard dose of MB. Results from Experiment 2 suggested that a dose of 30 g/m^2 with VIF plastic can reach complete control of the FW of carnation for the first 6.5 months after planting but DI reached ca. 23% 10 months later.

The soil treatments with metam-sodium were applied with irrigation water to seal the fumigant into the soil in Experiment 1, and with an injection system in Experiment 2. In addition, the dose of 80 g/m^2 used in Experiment 1 was increased to 100 g/m^2 in Experiment 2. However, the reduction of the pathogen in the soil up to 30 cm depth was not complete (6% in the upper layer) in the latter, in contrast with the reduction to undetectable levels achieved in Experiment 1. This brought about good control of FW in carnation (symptoms initiated ca. 9 months after planting, and final DI was ca. 30%) in Experiment 1, whereas disease onset occurred 4 months after planting and final DI was over 50% in Experiment 2. This poorer results could be attributed to inadequacies in the application system used in this experiment compared with that used in Experiment 1.

On the contrary, the application of 1,3-D + Chloropicrin in the irrigation system (Experiment 1) was much less effective (symptoms initiation ca. 3 months after planting, and final DI over 50%) than when it was injected in Experiment 2 (delay of symptoms appearance to 9.5 months after planting, and final DI of 12%), this treatment being more effective than MB.

CULTURAL AND BIOLOGICAL TREATMENTS

Since poultry manure is common in the area of carnation production, a treatment in Experiment 2 consisted of incorporation into the soil 5 kg/m^2 of fresh poultry manure followed by tarping with plastic for 4 weeks. The reduction of populations of *F. oxysporum* f.sp. *dianthi* in the soil was similar to that achieved by the MB (30g/m^2) + VIF treatment, probably due to the high temperature (45-52ºC) achieved in the soil. Consequently, there was a delay of 3 months in the initiation of symptoms compared to the untreated plots, and final DI was slightly under 50%, a moderate result in comparison to the effects of steam or the 1,3-D + Chloropicrin treatments.

INTEGRATED CONTROL

Due to the difficulties encountered when searching for methods of controlling soilborne plant pathogens such as *F. oxysporum* f.sp. *dianthi*, the integration of several methods with partial effectiveness seemed to be essential. T his approach was followed in Experiment 2 to some extent, since plastic tarping at the time of treating soil with fumigants or organic amendments increased the soil temperature over the 4 week period to close to solarization temperature, even though the time of tarping was not optimal in this regard.

Recently, Eshel *et al.* (2000) emphasized the importance of integrated control combining short duration (8 days) solarization and fumigation at low dose, and found relevant the sequence of these two methods of control in order to have synergic effects.

Other important approaches to study are the combination of eradication methods of control and the use of carnation cultivars with a high degree of resistance to the pathogen (Ben-Yephet *et al.* 1997), and the combination of those with the use of biocontrol agents, mainly non-pathogenic *Fusaria*, *Trichoderma* and *Streptomyces* (Gullino 1997; Pizano 1997).

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THE USE OF METHYL BROMIDE ALTERNATIVES IN CUT-FLOWER PRODUCTION IN PORTUGAL

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ABSTRACT

The cut-flower industry has grown steadily in Portugal in the last two decades. Today, about 1800 growers occupy an area of 1140 ha, of which 402 ha are outdoors. The main flowers produced in mainland Portugal are carnations, pinks, roses, gladioli, and gerbera. In Madeira Island and in the Azores, exotic flowers are produced, mostly *Strelitzia*, *Anthurium*, *Heliconia*, *Protea, Ornithogalum* and orchids. In 1999 Portuguese-exported flowers and live plants were worth € 12.4 million. Soilborne fungi, mainly *Fusarium oxysporum*, *Verticillium* sp., *Phytophthora* sp., *Sclerotinia* sp., *Rhizoctonia solani, Armillaria* sp. and *Rosellinia* sp., and plant parasitic nematodes, mostly *Meloidogyne hapla*, *M. incognita, M. javanica*, *Pratylenchus coffeae*, *Pratylenchus* sp., *Zygotylenchus* sp. and *Radopholus similis* seriously impair the cut flower production. Experiments so far conducted in mainland Portugal indicated that soil solarization, alone or combined with low doses of chemicals to control soilborne plant pathogens, is an alternative to the use of methyl bromide.

Keywords: Portugal, Madeira Island, Azores, cut flower, *Meloidogyne*, *Pratylenchus P. coffeae*, *Radopholus similis*, *Zygotylenchus*, *Fusarium oxysporum*, *Phytophthora*, *Verticillium*, *Sclerotinia, Rhizoctonia*, *Armillaria, Rosellinia*.

INTRODUCTION

Portugal lies on the extreme western border of the European continent. It is rimmed on the east and north by Spain and on the west and south by the Atlantic Ocean. To the west and south-west lie the Atlantic islands of the Azores and Madeira, which are part of metropolitan Portugal. Occupying about 15% of the Iberian Peninsula, Portugal has a total area of 88,500 km^2. Despite its small size, the country displays a great diversity of geographical features. It is divided by the Tagus River between a northern mountainous region with narrow valleys and the southern plains and tablelands with broad river basins and few hills.

There are three major ecological regions. The NW or Atlantic region, roughly embracing the littoral and coastal uplands northwards from the Tagus River, which enjoys a mild climate with abundant and reasonably well-distributed rainfall, a cool winter and relatively short summer dry period. This is the most intensively farmed region in the country. The Northeast region, locally known as Trás-os-Montes, consisting of a number of ecologically different zones, depending on altitude and the relative influence of the Atlantic, Continental and Mediterranean-type climates. Finally, the southern zone of Alentejo comprising that part of the country south of the River Tagus and extending north to include part of the Beira Baixa, has essentially a milder Mediterranean-type climate with rainfall decreasing as one proceeds southwards.

Madeira, composed of the islands of Madeira and Porto Santo, lies in the Atlantic about 1,000 km south-east of continental Portugal. It has an area of 796 km^2 and its climate is influenced by the trade winds with mild, Mediterranean type conditions and relatively high temperatures. Precipitation, rare in summer, seldom exceeds 640 mm.

The Azores archipelago, composed of nine islands in three widely separated groups, lie in the Atlantic. The island nearest to Portugal, São Miguel, is 1,190 km from Cabo da Roca. With a total area of 2,305 km^2, the Azores also have a mild climate, moderated by the Gulf Stream, and an average precipitation of 1,143 mm annually.

THE CUT FLOWER INDUSTRY IN PORTUGAL

Owing to favourable edaphic and climatic conditions occurring in the country, cut-flower production in Portugal has been increasing steadily since the sixties (Lança *et al.* 1988; Barroso & Monteiro 1997; Pires 1999). The most important crops are carnations, pinks, roses, gladioli, gerbera, chrysanthemum and lilies. Exotic flowers such as the anthurium, the strelitzia, the orchid and the protea are produced mainly in the Madeira and Azores islands.

The size of the cut-flower farms owned by ca. 1,800 growers varies between 0.05 ha and 20 ha, and most of the greenhouses are not heated. Portuguese foreign trade of live plants and flowers, excluding foliage, attained € 53.5 million in 1999. Flower exports, mostly to Holland, France, United Kingdom, Germany and Spain, were worth € 12.4 million (Anon. 2001).

Data related to the production of cut flowers in the nine Portuguese agrarian regions are presented in Table I.

Table 1: Cut flower production in Portugal.

Agrarian regions (Number of growers)	Acreage (ha)		Usual soil treatments	Crops produced
	Protected	Outdoors		
Beira Litoral (160)	149.5	49.1	Methyl bromide, dazomet, metam-sodium, fenamiphos, oxamyl, ethoprophos, Ret-Flo Px 357	Carnations, pinks, roses, gerbera, chrysanthemums, lilies, bulbs
Alentejo (58)	3.8	40.2	Methyl bromide, metam-sodium, dazomet.	Carnations, pinks, gladioli, lilies, chrysanthemum, gerbera.
Entre Douro e Minho (781)	230.0	106.0	Metam-sodium, dazomet, steam	Carnations, pinks, roses, gerbera, gladioli, lilies, Alstroemeria
Beira Interior (37)	1.3	3.7	Methyl bromide, dazomet	Carnations, pinks, gladioli, zinia gerbera
Algarve (66)	27.0	17.0	Dazomet, metam-sodium	Carnations, pinks, roses, gerbera
Trás-os-Montes (151)	41.7	1.6	Dazomet, metam-sodium	Carnations, pinks, gladioli, gerbera, Gipsophila
Ribatejo e Oeste (286)	250.0	70.0	Methyl bromide, dazomet, metam-sodium	Carnations, pinks, roses, gladioli, gerbera, Gipsophila, tulips, chrysanthemum and lilies
Azores (60)	5.0	69.0	Usually no soil treatments are made	Carnations, roses, Anthurium, Gerbera, Protea, Strelitzia, Hydrangea
Madeira (180)	30.0	45.0	Dazomet, propamocarb, carbendazim, fosetyl-Al	Protea, Strelitzia, Heliconia, Ornithogalum, Anthurium and orchids
Total:	**738.3**	**401.6**		

Soilborne plant pathogens

The occurrence of edaphic plant pathogens, mainly nematodes and fungi, frequently constrains cut-flower production in Portugal. The root-knot nematodes *Meloidogyne hapla, M. incognita,* and

M. javanica have been found associated with the decline of various crops such as roses, carnations, and strelitzia (Reis 1985). Root lesion nematodes (*Pratylenchus* spp.) affect the development of carnations, *Dahlia* and glasshouse grown *Alstroemeria*. The bulb and stem nematode *Ditylenchus dipsaci* seriously affected a carnation crop. Root damage caused by *Zygotylenchus* sp. was found in *Gypsophila elegans* plantations. The foliage of chrysanthemums and dahlias were found sporadically invaded by the leaf nematode *Aphelenchoides ritzemabosi*. *Anthurium* production in Madeira Island was seriously affected by *Pratylenchus coffeae*, *Pratylenchus* sp. and by the burrowing nematode *Radopholus similes*, introduced recently in the island with imported *Athurium* propagation material (Cravo & Pestana 2001; Pestana & Cravo 1999). Attempts to eradicate *R. similis* from the island have been unsuccessful so far.

Plant pathogenic soilborne fungi also frequently impair the production of many crops. In mainland Portugal, the more troublesome fungi are *Fusarium oxysporum*, *Verticillium* sp., *Phytophthora* sp., *Sclerotinia* sp. and *Rhizoctonia solani.* In Madeira Island, *Pythium* sp., *Verticillium* sp., *Armillaria* sp. and *Rosellinia* sp. are the most damaging soil fungi, the last two occurring frequently in *Proteaceae* groves established in soils previously occupied by forest trees (Moura & Rodrigues 2001; Sardinha 2001).

DISCUSSION AND CONCLUSIONS

The control of soilborne plant pathogens is not an easy task. So, to control diseases caused by soilborne plant pathogens, many carnation, pink, lily and gerbera producers use methyl bromide (MB) in their greenhouses because no other chemical method available has the same broad spectrum of activity. However, soil solarization can be an alternative to MB for the disinfestation of those soils.

Data related to soil solarization trials so far conducted in localities ranging from northern to southern Portugal indicate that this technique can give satisfactory to good control of the major soilborne plant pathogens such as phytoparasitic nematodes *viz*. *Meloidogyne* spp., *Pratylenchus* spp., fungi, *e.g*. *Fusarium oxysporum* f. sp. *gladioli*, and weeds. Nevertheless, the high number of foggy mornings occurring in August in the littoral and coastal uplands of mainland Portugal diminishes the effectiveness of soil solarization. In these cases, the efficacy of the incorporation in the soil of small doses of appropriate agrochemicals before solarization should be studied.

Within mainland Portugal in the hottest months (June, July, August) the monthly average daily global solar radiation reaching the land varies between 22.9 MJ m^{-2} and 28.8 MJ m^{-2} (Reis 1997; Reis 1998). This impressive amount of free and inexhaustible energy can profitably be used to disinfest sick soils without the danger of causing environmental hazards. Soil solarization studies must be pursued in Portugal in order to optimise our knowledge and practice of this technique for use in many diverse ecological zones.

Data on the effectiveness of soil steaming to disinfest soils is still very scarce in Portugal. More information is needed relating to its efficacy according to exposure time, soil type and target micro-organisms.

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ALTERNATIVES TO METHYL BROMIDE FOR CUT-FLOWERS

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ABSTRACT

The requirement to phase-out methyl bromide (MB) in the cut-flower sector needs more attention than in other sectors in order to identify fully effective solutions that are environmental friendly and technically sustainable. Resistant varieties, soilless cultivation, steam, soil solarization, biocontrol agents and chemicals have been evaluated as potential alternatives and can be considered as components of a global strategy to replace MB in cut-flower production.

Keywords: soil disinfestation, ornamentals, resistant varieties, soilless cultivation, steam, soil solarization, biocontrol agents, chemical control.

INTRODUCTION

Since 1994, two years after the inclusion of methyl bromide (MB) in the list of ozone depleting substances under the Montreal Protocol, intensive collaboration was established between the Italian Ministry of Environment and Territory and the Department of Plant Pathology of the University of Torino in order to identify short and long-term solutions to reduce the use of MB and to ensure compliance with the international and European requirements.

The research activities carried out by Di.Va.P.R.A. and financed by the Ministry for the Environment and Territory, have focused particularly on the Italian vegetable and ornamental crops due to the high consumption of MB in these two production sectors, which in 1994, were estimated to consume 6,970 tonnes for soil disinfestation.

The replacement of MB in the ornamental sector has became even more complicated than in the vegetable sector due to the specific features of the sector itself (Katan 2000). The intensive and highly specialized cultivation systems lead to a build-up of detrimental biological factors in the soil (fungi, nematodes, insects). The farms, located mainly in urban areas and usually of small size, make it difficult to use other chemicals not only because of their toxic properties, but also because of their unpleasant smell. Moreover, the high capital and operational costs oblige growers to reduce the risk of losses of production through the use of MB against soil-borne plant pathogens (Garibaldi & Gullino 1995; Katan 2000). Many other strategies that could be adopted to control soil borne pathogens (resistant varieties, innovative cropping systems, physical and biological soil properties management, climate control measures and field hygiene) are not yet considered by the growers as fully effective solutions (Gullino & Clini 1998, 1999).

AVAILABLE ALTERNATIVES

The research activities carried out by Di.Va.P.R.A. aimed to develop new, alternative technologies that would be reliable from technical, human health, economical and environmental points of view and feasible under different climatic and cultural situations. The results obtained, even if in some cases further confirmation and improvements are needed, represent effective mid- and long-term alternative solutions that will substitute for the use of MB.

Resistant varieties

Resistant or tolerant varieties to one or few specific pathogens (and races) are already available for several crop species. In most cases, new varieties are still being developed using plant breeding.

Table 1: Resistant clones to 4 pathotypes of *F.dianthi* selected in 1995-1999 (adapted from Minuto *et al.*, 2000).

Breeder company	**Commercialized resistant clones (name of cultivar in brackets)**	**Not commercialized resistant clones**
Taroni	3191 (Coralie)	2666, 25-XI, 1542, 40, 33, 2529, 140, 178, 66, 236, 252, 254
Santamaria	31 (Shiva)	2506, 237, 20965
Gigante	308 (Rigoletto), 687 (Tango), Alex (Alexander), Callas (Callas)	1519, 943
Di Giorgio	91QC51 (Oklahoma), 92QFS19 (Pamplona), D135 (Placido), D224 (Silvestro), D92 (Sulmona), D239 (Graziano), D233 (Torpedo), E49, B140 (Koala)	B201, B175, B118, C42, N392, D229, D236, D71, O145, O519, E104, E65, F189, F231, F99

The use of modern biotechnology is regarded as a quicker and more effective method for the introduction of resistance genes. The easy application of resistant plants which have minimal environmental impact, and the possibility of combining resistant plants with other control methods, makes resistant varieties a feasible alternative. The major limits are the limited spectrum of activity and the high cost of selection of multiple-resistant varieties with appropriate commercially acceptable quality and yield.

In Italy, resistance of carnation varieties selected by several Italian breeders has been determined annually to four pathotypes of *Fusarium oxysporum* f. sp. *dianthi* (1, 2, 4, 8). During the period 1995-1999, this programme showed that a large number of varieties were resistant to pathotypes 1 and 8, a low number were resistant to pathotypes 2 and 4 and a very limited number were resistant to all pathotypes (Table 1) (Minuto *et al.* 2000).

Soilless cultivation

Soilless cultivation is rapidly expanding in Italy on high value crops (rose, carnation, gerbera, basil, lettuce, for example) (Gullino & Garibaldi 1994; Serra 1994; Pergola & Farina 1995), albeit at a lower rate (200 Ha) as compared with Northern Europe (Van Os & Stanghellini, 2001). Soilless culture offers the advantages of increased productivity, easier yield quality management and reduction in conventional soil-borne pathogens. The environmental impact of open run-to-waste systems should be limited in order to reduce the release of nutrient solutions. In this regard the closed soilless systems seem to be the best solution, even when disinfesting the recirculating nutrient solutions increases the cost of investment. Moreover, the possible establishment of new diseases seems a real risk that needs to be taken into account (Stanghellini & Rasmussen, 1994).

To avoid the risks of diseases spreading, recent research evaluated active (metalaxyl, sodium dichloroisocianurate [Na-DIC]; UV radiation) and passive (slow sand filtration) systems to control *Phytophthora cryptogea* spread in a gerbera soilless crop (table 2) (Garibaldi *et al.* 2001). Metalaxyl application was able to provide good results but could be complicated to operate when the nutrient solution is completely discharged to waste in order to maintain an unacceptable level of chemical conditions (electric conductivity, pH). In this case, the environmentally negative risk could be due to the presence of chemical residues in a discharging nutrient solution. Moreover, the use of a chemical with specific mode of action such as metalaxyl increases the risk of the onset of disease resistance.

Use of chlorinated compounds, such as chlorine gas or Na-DIC, are sometimes recommended for the disinfection of nutrient solutions (Poncet *et al*. 1999) but these may not be suitable. In Italy, chlorine gas is considered toxic and therefore users must comply with strict storage, handling and transportation rules. Moreover, the risk of exposure to workers in increased when chlorine gas and chlorinated compounds are used. Finally, the results obtained highlight the risk of phytotoxicity caused by the application of a chlorinated compound such as Na-DIC. On the contrary, the encouraging results obtained using UV radiation or sand filtration seem to permit a non-chemical and successful phytosanitary management of recycled nutrient solutions.

TABLE 2: Effect of active and passive water disinfection against *P. cryptogea* on gerbera (cv Goldie) (adapted from Garibaldi *et al.*, 2001).

Treatment	**Percent of infected plants at days after transplant**							
	158		**211**		**218**		**224**	
Sand filtration	2.9	a°	4.5	a	4.5	a	5.4	ab
U.V. radiation	3.7	a	5.4	a	6.3	ab	8.1	ab
Na-DIC *	3.6	a	22.5	a	35.1	b	41.4	c
Metalaxyl	0.0	a	0.0	a	0.0	a	0.9	a
Control	9.1	a	19.8	a	25.3	ab	33.4	bc

* 50 ppm until 03/30 and 10 ppm later on; ° Means of the same column followed by the same letter do not statistically differ following Duncan's Multiple Range Test (P =0.05)

Steam

Steam can achieve good results against several pests, diseases and weeds without any residue soil contamination and with minimal wait-period before planting. Its high efficacy causes a "biological vacuum" and the consequent risk of pathogen recolonization ("boomerang effect"). Moreover, a release of heavy metals, a decomposition of organic matter and consequently accumulation of ammonia, a solubilization of inorganic compounds and a modification of the solubility and availability of the nutrient elements, could cause unpredictable phytotoxicity problems. Steam adoption is currently available for small surfaces (benches, seedbeds, soilless cultivation, for example), firstly because it is generally applied with a discontinuous application method requiring some in-between time following treatments. Secondly, steam is a high energy-consumer (1.5-2.5 gasoline/m^2) and therefore contributes to the global warming.

Soil solarazation

Soil solarization, a well known hydrothermal process (Katan & De Vay 1991), could be adopted for cut-flower production in less intensive cropping system. This strategy takes no less than 4-6 weeks to be successful, either alone or combined with chemicals such methyl isotiocyanate generators. Unfortunately, the period of time for carrying out soil solarization can coincide with the growing season, reducing its possible application in practice.

Bench solarization and solarization in greenhouses are new applications that may help expand its use to even cooler climatic areas (i.e. North-Central Italy) and seasons (Gullino *et al.*, 1998; Katan, 2000) where solarization has not traditionally been used. Solarization offers many positive features, including an Increased Growth Response, relatively low cost and the preservation of the beneficial soil flora and fauna. Among the major constraints are climate and meteorological unpredictability, the large amount of irrigation water required to increase the thermal conductivity of the soil (especially sandy soils). In addition, solarization has a limited spectrum of activity against pathogens, particularly nematodes, compared to MB and steam treatments (Katan & De Vay 1991).

Biological control

Although several biocontrol agents (BCAs) have been successfully exploited to control soil-borne pathogens, at present they cannot be considered a viable alternative to MB for soil fumigation due to the very limited number of registered BCAs, their very narrow spectrum of activity, their short formulation shelf life and their low commercial availability (Fravel *et al.* 1999). Hopefully in the future, registered BCAs could play a role in soil disinfestation, when specific problems need to be solved (Garibaldi & Gullino, 1995). The most positive effects of using BCAs are the possibility of using them to control pathogens not yet controlled by other traditional methods, their low environmental impact (when recombinant micro-organisms are not used) and the total absence of chemical residues.

In cut-flower production, several microrganisms are now well-known as effective antagonists against soil-borne pathogens: antagonistic *Fusaria* are effective against *Fusarium* wilt of carnation and chrysanthemum; a selected strain of *Agrobacterium rhizogenes* can easily control the *Agrobacterium tumefaciens* infection, but unfortunately few of them are now registered in Italy and South European countries.

A strategy able to easily improve the transfer into practice of BCAs for cut-flowers could be their application combined with chemicals and/or resistant varieties. It has been demonstrated that antagonistic *Fusaria* can be applied combined with benzimidazoles, when naturally resistant to these fungicides, to control *Fusarium* wilt of carnation, improving the disease tolerance of adopted varieties (Table 3)

TABLE 3: Effectiveness of application of different BCAs against *Fusarium* wilt of carnation, artificially inoculated ($5x10^3$ CFU/g of soil), combined with chemical control and genetic resistance varieties at 92 days after the transplant (adapted from Garibaldi *et al*., 1990).

Varieties	BCAs 10^5 CFU/g of soil	Benomyl g/m^2	Disease index (0-100)		Percent healthy plants	
Manon	-	-	69	d	27	d
Cantalupo	-	-	49	c	38	cd
Manon	S*	-	45	c	47	c
Cantalupo	S	-	20	b	70	b
Manon	RB**	-	40	c	47	c
Cantalupo	RB	-	25	b	65	b
Manon	S	20	10	a	86	a
Cantalupo	S	20	4	a	95	a

*S = sensitive to benomyl; RB = resistant to benomyl**° See table 2.

Chemical control

The chemical products for soil disinfestation may have a “broad spectrum of activity” (fumigants) or a “more specific spectrum of activity” (fungicides and nematicides). Among the first group, the methyl isothiocyanate (MITC) generators are the most popular. Metham sodium as a liquid soil chemical, and dazomet as a solid, are effective for controlling weeds and soil-borne pathogens, principally fungi, and a limited number of parasitic nematodes species, but must be applied when soil temperatures are not below 12-15°C. Metam sodium’s use is relatively low cost when carried out by the growers themselves, but it has a low efficacy against several vascular diseases and some specific soil-borne pathogens. Nematodes can often be missed due to the non-uniform distribution in the soil or to the climate and meteorological unpredictability. Moreover the long waiting period between treatment and planting, the additional requirement for plastic mulch to improve efficacy and reduce environmental impact, and the need to dispose of the plastic, all reduce the grower acceptance of metam sodium.

Metam sodium, used recently in a gerbera greenhouse against root rot caused by *Phytophthora cryptogea*, showed that MB applied at 60 g/m^2 or at 40 g/m^2 under virtually impermeable film controlled root rot satisfactorily, while metham sodium applied at 192 g/m^2 without plastic mulch did not provide satisfactory disease control. Moreover, the same fumigant provided better results when applied at 96 g/m^2 under plastic mulch (Table 4) (Minuto *et al*. 2000). A more specific soil disinfectant, 1,3-dichloropropene (1,3-D) applied mainly by injection, provided effective control of nematodes, insects, some weeds and some pathogenic fungi. During the application of 1,3-D, the soil must remain covered with plastic mulch to improve its efficacy and to reduce worker exposure (Lamberti *et al*. 2000).

TABLE 4: Effectiveness of different soil treatments against *Phytophthora cryptogea* on gerbera (Albenga, 1997 - 1998) (adapted from Minuto *et al*., 2000).

Treatment	**Percent dead plants at days after transplant**				**Number of flowers per plant**	
	106	**213**	**310**	**386**		
-/-/-	7.9 b°	11.2 c	26.1 b	44.5 b	22.1	a
BM/60/PE	3.0 a	3.1 a	11.4 a	17.2 a	19.0	b
BM/40/LMG	2.1 a	3.0 a	12.0 a	19.9 a	20.1	ab
MS/192/-	5.4 ab	6.1 b	15.5 a	30.2 b	19.6	ab
MS/96/PE	4.8 ab	3.3 a	13.1 a	26.2 ab	18.6	b
MS/96/LMG	5.7 ab	5.0 ab	13.2 a	26.5 ab	22.4	a

° Means of the same column followed by the same letter do not statistically differ following Duncan's Multiple Range Test (P =0.05)

CONCLUSIONS

The available alternatives evaluated to replace MB for cut-flower production still need an intermediate stage for testing the results obtained under experimental conditions on a commercial scale. The examples reported above indicate that there can be negative environmental effects and enhanced phytotoxicity risks. The availability of alternatives must be considered when evaluating the efficacy as the ability to transfer the treatment to growers is essential. Despite these comments, resistant varieties, soilless cultivation, steam, soil solarization, biocontrol agents and chemicals can all be considered as components of a global strategy that can replace MB in cut-flowers production.

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ALTERNATIVES TO METHYL BROMIDE FOR CUT-FLOWER PRODUCTION IN GUATEMALA

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ABSTRACT

The use of MB in Guatemala for crop production continued to increase until 1997 when a programme testing alternatives commenced. This study on *Anthirrynum sp*., commonly called Snap Dragon, showed that weeds were best controlled with either steam or metam sodium as alternatives to MB. Steam was the best at controlling damping-off disease. Metam sodium had little effect on *Pithium sp* and soil nematodes and therefore its future use is limited. Although steam cost 14% more than the regular dose MB, steam could be a benefit to some growers as production without synthetic chemicals is valued in some international markets.

Keywords: Guatemala, methyl bromide, *Anthirrynum,* steam, metam sodium, *Pithium*

INTRODUCTION

In Guatemala, methyl bromide (MB) is mainly used for production of crops such as melon, cutting flowers, tomato, broccoli, tobacco and seedlings. The consumption of MB increased from 43 tonnes in 1993 to 455 tonnes in 1997 due mainly to an expansion in the area planted with melon. Recently, MB consumption was reduced by approximately 50% compared to 1997 due to the availability of alternatives.

About 175 ha of cut-flowers from different species are planted in Guatemala of which 60% are treated with 42 tonnes of MB a year in order to minimise the risk of losses due to soil diseases. The objectives of this study were to evaluate alternatives to MB for the control of soil organisms capable of causing economic losses in the production of cutting flowers, and to determine the cost of production for each alternative evaluated

METHODOLOGY

The investigation was carried out in the fields of the Pamputik Company, located in Pastores, Department of Sacatepéquez, from May to September 1999. The variety of cut-flower used was *Anthirrynum sp*., commonly called Snap Dragon.

The following variables were analysed: Damping-off (*Pithium sp)*; presence of weeds, nematodes; production quality; and cost of treatments. A randomised complete block design with 6 treatments and 4 replications was used. The experimental unit was a 1 x 10 m plot. Each block was 90 m^2 and total area was 400 m^2. Steam was generated from a boiler. The treatments evaluated were: Steam at 90°C for 30, 45 or 60 minutes; Metam Sodium, 1000 l/ha (sodium monomethyl dithiocarbamate); average-dose MB at 232 kg/ha to reduce pathogens; and regular-dose MB at 464 kg/ha.

RESULTS

Control of weeds: Data were collected twice, 10 and 25 days after transplant. In the first data collection, steam treatments were statistically similar, regardless of time, to the metam sodium treatment. The regular MB treatment suppressed weeds but the average dose of MB was not significantly different to the control with a total of 1360 weeds per m^2. A similar situation occurred in the second data collection at 25 days.

Table 1: Weeds per m^2 , 10 and 25 days after transplant.

Treatments	10 days after transplant	25 days after transplant
Steam 30 minutes	20 b	27 b
Steam 45 minutes	18 b	19 b
Steam 60 minutes	05 b	10 b
Metam Sodium	12 b	19 b
Methyl Bromide 464 kg/ha	00 b	09 b
Methyl Bromide 232 kg/ha	1,360 a	1695 a

Duncan multiple range test

Control of "Damping-off" (*Pithium sp.)*: Steam and the regular dose MB controlled the pathogen adequately and reducing their incidence significantly. Metam sodium and the average MB treatments allowed the disease to increase significantly affecting 3 to 4% of the plants that died because of presence of *Pithium sp*. (Table 2).

Table 2: Control of Damping-off (%) with different treatments.

Treatments	Percentage damage
Steam 30 minutes	0.10 c
Steam 45 minutes	0.17 bc
Steam 60 minutes	0.20 bc
Metam Sodium	3.00 ab
Methyl Bromide 464 kg/ha	0.40 bc
Methyl Bromide 232 kg/ha	4.00 a

Duncan Multiple range test

Control of Nematodes: Although the analysis showed the presence of nematodes capable of damage the crop, the low populations did not represent a problem. *Rhabditis* nematode populations increased significantly after steam applications. They are reported to not be plant parasites but parasites of organic matter.

Production quality: This factor is determined directly by the length of the shoots and flowering vigour. With exception of the average MB dose, the treatments did not show significant difference in the quality obtained.

Cost per treatment: Steam treatments for 30, 45 and 60 minutes cost US$0.34 per m^2, 0.37 per m^2 and 0.42 per m^2 respectively. Metam sodium cost US$0.35 per m^2. Average dose MB cost US$ 0.26 per m^2 and the regular dose US$ 0.37 per m^2. This data demonstrate that steam has a similar cost to MB with similar efficiency and therefore can be considered as a good alternative.

CONCLUSIONS

Weed control, steam and metam sodium were all equally effective as alternatives to MB used at the recommended dose. Steam was the best at controlling damping-off. Reduced-dose MB cannot be recommended in place of an alternative. Metam sodium was a good choice for weed control but had little effect on *Pithium sp* and soil nematodes and therefore its future use is limited. Although steam cost 14% more than the regular dose MB, production without synthetic chemicals could be a benefit for some growers as it adds value in some international markets.

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ALTERNATIVES TO METHYL BROMIDE FOR CONTROL OF ANNUAL AND PERENNIAL WEEDS

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ABSTRACT

Two field experiments were conducted in 2000 and 2001 in northern Greece to evaluate the effect of application time of methyl bromide (MB), metham sodium and dazomet against certain annual and perennial weeds. The first experiment was established on 21 November 2000 and the second on 13 June 2001. The results of the first experiment indicated that all fumigants at 4 months after treatment (MAT) gave excellent control of the winter annual weeds *Lamium amplexicaule, Stellaria media,* and *Veronica hederifolia* and very good control of the summer annual weeds *Chenopodium album*, *Xanthium strumarium,* and *Datura stramonium*. Also, all treatments at the same time reduced stem emergence of the perennial weeds *Cynodon dactylon, Sorghum halepense,* and *Convolvulus arvensis* by 85-100% compared with that of the untreated control. However, at 6 MAT, MB was the only treatment that reduced by 90-99% stem emergence of the three previously mentioned perennial weeds, while the *C. dactylon, S. halepense* and *C. arvensis* control obtained by the rest of the treatments ranged from 60 to 79, 9 to 49, and 62 to 84%, respectively. In the second experiment, all treatments at 1, 2, and 3 MAT gave excellent control of *Portulaca oleracea* and very good control of *X. strumarium* and *D. stramonium*. Metham sodium and dazomet, in contrast to the results of the first experiment, gave very good control of *C. dactylon* and *S. halepense* and similar to that provided by MB. These results show clearly that metham sodium and dazomet could possibly be used as an alternative to MB for weed control in vegetable production, but they should be applied in early summer rather than in late autumn for better weed control.

Keywords: Dazomet, metham sodium, methyl bromide, soil fumigants.

INTRODUCTION

A recent survey conducted in northern Greece indicated that the annuals *Amaranthus* spp., *C. album*, *Conyza* spp., *Digitaria sanguinalis*, *Echinochloa crus-galli*, *Galinsoga parviflora*, *Poa annua*, *P. oleracea*, *Setaria* spp., *Solanum nigrum*, *S. media, Veronica* spp.*,* and *Urtica* spp.*,* as well as the perennials *C. dactylon, Cyperus* spp. and *C. arvensis* were among the most commonly found weeds in greenhouses (Eleftherohorinos & Giannopolitis 1999).

Many of the abovementioned weeds are also commonly found in arable crops and in many vegetable crops grown under field conditions. They are considered to reduce crop yields and lower the quality of crop products by competing with crops primarily for soil nutrients and moisture but also for light and carbon dioxide. Some of these weeds affect crop growth indirectly by harboring insect, nematode and fungus organisms that attack crop plants. So, their control is basic for efficient and profitable agriculture.

Methyl bromide (MB) has been extensively used worldwide as a broad-spectrum fumigant in the production of many vegetable crops. This is because it is the most effective soil fumigant against nematodes, insects, diseases, and weeds. Concerning its herbicidal activity, results published in the literature and results of our recently survey conducted in greenhouses of northern Greece, indicate that MB has excellent efficacy against the annuals *Abutilon*, *Amaranthus*, *Avena*, *Chenopodium*, *Conyza*, *Datura*, *Digitaria*, *Echinochloa*, *Galinsoga*, *Papaver*, *Poa*, *Portulaca*, *Setaria*, *Solanum*, *Stellaria,* and *Urtica* and very good efficacy against the perennials *Sorghum, Cynodon, Cyperus,* and *Convolvulus* (Zhang *et al.* 1997).

Since most of the use of MB are going to be phased out by 2005, mainly because of the detrimental effect of MB on the ozone layer (Albritton & Watson 1992; Ohr *et al.* 1996), this research was conducted in Greece aiming to find alternatives to MB against weeds. The objective of this study was to evaluate the effect of application time and method of metham sodium and dazomet against certain annual and perennial weeds.

MATERIALS AND METHODS

Two field experiments were conducted in 2000 and 2001 on a silty clay loam soil of the University Farm of Thessaloniki, northern Greece. The first experiment was established in an area infested with natural populations of winter annual weeds (*L. amplexicaule, S. media*, *V. hederifolia),* summer annuals (*C. album*, *X. strumarium*, *D. stramonium)*, and the perennial *S. halepense*. The area of the second experiment was infested with natural populations of *X. strumarium*, *D. stramonium, P. oleracea,* and *S. halepense*. The area in both experiments was technically infested with *C. dactylon* and *C. arvensis* by spreading evenly and incorporating afterwards their underground propagation organs in soil.

The first experiment was established on 21 November 2000, while the second one on 13 June 2001. The area before their establishment was irrigated and four days later was cultivated with a rotovator in a 7-10 cm soil depth. The fumigants were applied afterwards to the soil according to the label instructions and to the recommended practices. So, metham sodium (Vapam 32.7 SL, 2,500 l/ha) was applied with the irrigation water (10 mm of water), while dazomet (Basamid 98 G, 600 kg/ha) and MB (680 kg/ha) were applied by even broadcast of its granules and by fumigation under polyethylene transparent sheet, respectively. The soil temperature at their application and during the following 12 days ranged from 12 to 16 and from 26 to 29^{o}C in the first and second experiment, respectively.

Immediately after their application, the plots treated with dazomet were cultivated with a rotovator in a 7-10 cm soil depth for its incorporation, and then all plots, except those treated with MB (covered with polyethylene transparent sheet), were irrigated with 10 mm of water. Four hours later, three of the six plots treated with dazomet were covered with a polyethylene transparent sheet. This was made to prevent loss of methyl isothiocyanate (MITC), the primary dazomet break down bioactive agent. The experimental area was irrigated for 12 consecutive days to keep the soil wet. The polyethylene transparent sheet was removed from the MB treated plots four days after its application, while that from the dazomet treated plots eight days later (12 days after its application). Then, all experimental plots were cultivated with a rotovator in a 7-10 cm soil depth.

A randomized complete block design was used in both experiments. There were three replications (plots) for each treatment. Plot size was 1.5 by 6.5m, and an alley 1m wide separated all plots. The efficacy of all treatments was evaluated by weed measurements in an 8m^2 area of each plot at 3, 4, 5, and 6 MAT in the first experiment, and at 1, 2, and 3 MAT in the second experiment. The data before the analysis of variance were square root transformed.

RESULTS AND DISCUSSION

In the first experiment, all treatments at 3, 4, and 5 MAT gave very good to excellent control of the winter weeds *l. Amplexicaule, s. Media* and *v. Hederifolia* (table 1). Also, all treatments at 4 MAT, gave very good to excellent control of summer annual weeds *c. Album*, *x. Strumarium* and *d. Stramonium* (Table 2). However, at 6 MAT, MB was the only effective treatment (98-99% control) against these weeds, while the control obtained with the other treatments was significantly lower. In general, metham sodium gave better control of the three summer annual weeds than dazomet covered with polyethylene transparent sheet, while dazomet applied with irrigation provided intermediate weed control. All treatments at 4 MAT reduced significantly stem emergence of the perennial weeds *C. dactylon, S. halepense* and *C. arvensis* compared with that of the untreated control (Table 3). However, at 6 MAT, MB was the only treatment that had reduced by 90-99%

stem emergence of the three previously mentioned perennial weeds. Metham sodium at the same time reduced stem emergence of *C. dactylon, S. halepense* and *C. arvensis* by 79, 49 and 84%, respectively. The corresponding reduction due to dazomet applied with irrigation was 62, 9, 62%, while that caused by dazomet covered with polyethylene transparent sheet was 60, 16 and 64%.

In the second experiment, all treatments at 1, 2, and 3 MAT gave excellent control of *P. oleracea* and very good control of *X. strumarium* and *D. stramonium* (Table 4). Metham sodium and dazomet applied either way, in contrast to the results of the first experiment, caused significant reduction of *C. dactylon* and *S. halepense* stem emergence and similar with that provided by methyl bromide (Table 5). Their efficacy against *C. arvensis* was not evaluated due to its low density recorded in all plots.

These results show clearly that metham sodium and dazomet could possibly be used as an alternative to MB for weed control in vegetable production. However, although both are typically applied in the fall, the results of this study showed clearly that their application in early summer provided better weed control compared with that obtained after their application during autumn. The better soil environmental conditions that prevailed after their application in early summer may favor seed germination and bud sprouting of weeds and consequently increase their susceptibility to the fumigants applied. It is well known that weeds at seed germination or bud sprouting stage are more vulnerable to most chemicals used than at seed or bud dormancy.

It is worth mentioning that some of the following considerations should be taken into account before widespread use of dazomet and metham sodium (Noling & Beker 1994): 1) They must be applied in large quantities which is difficult to handle, 2) They depend on irrigation for their activation after application, 3) They have a reduced effectiveness against some common weeds (*Solanum* and *Cyperus*), *4*) They are readily leached and consequently have a high potential for groundwater contamination, 5) They have a short residual activity which means a short lasting weed control efficacy (particularly against summer weeds after their application in fall).

Table 1: Efficacy of fumigants tested against the annual winter weeds (Experiment I).

Treatments	*S. media*			*V. hederifolia*			*L. amplexicaule*		
	Plants/8m^2								
	Months after treatment								
	3	4	5	3	4	5	3	4	5
Methyl bromide	1b[1]	3b	5b	0b	0b	0b	0b	0b	0b
Metham sodium	0b	2b	3b	0b	0b	0b	0b	0b	0b
Dazomet (irrigated)	1b	3b	4b	0b	0b	0b	0b	0b	0b
Dazomet (covered)	1b	2b	5b	0b	1b	2b	0b	1b	2b
Control	24a	135a	138a	18a	32a	37a	19a	63a	67a

[1]Treatment means of the same column followed by the same letter are not significantly different according to the LSD test at P=0.05.

Table 2: Efficacy of fumigants tested against the annual summer weeds (Experiment I).

Treatments	*C. album*			*X. strumarium*			*D. stramonium*		
	Plants/8m^2								
	Months after treatment								
	4	5	6	4	5	6	4	5	6
Methyl bromide	3b[1]	1c	1d	0d	0b	0b	0b	0c	0d
Metham sodium	1b	2bc	2cd	5c	29a	46a	0b	0c	5c
Dazomet (irrigated)	3b	4bc	5bc	11bc	21a	22a	1b	6b	6bc
Dazomet (covered)	3b	6b	8b	14b	38a	40a	0b	10b	12b
Control	36a	62a	53a	38a	48a	44a	20a	28a	24a

[1]Treatment means of the same column followed by the same letter are not significantly different according to the LSD test at P=0.05.

Table 3: Efficacy of fumigants tested against the perennial weeds (Experiment I).

Treatments	*S. halepense*			*C. dactylon*			*C. arvensis*		
	Stems/8m^2								
	Months after treatment								
	4	5	6	4	5	6	4	5	6
Methyl bromide	0c[1]	0d	1c	0b	2d	12c	2bc	10b	15c
Metham sodium	0c	10c	57b	0b	9cd	43bc	0c	14b	23bc
Dazomet (irrigated)	2bc	11c	103a	5b	27c	84b	2bc	15b	54b
Dazomet (covered)	5b	27b	95ab	5b	59b	90b	4b	29b	49b
Control	44a	89a	113a	83a	203a	222a	47a	122a	144a

[1]Treatment means of the same column followed by the same letter are not significantly different according to the LSD test at P=0.05.

Table 4: Efficacy of fumigants tested against the annual summer weeds (Experiment II).

Treatments	*P. oleracea*			*X. strumarium*			*D. stramonium*		
	Plants/8m^2								
	Months after treatment								
	1	2	3	1	2	3	1	2	3
Methyl bromide	0b[1]	0b	0b	0b	1b	1b	0b	2c	2c
Metham sodium	0b	0b	0b	0b	1b	1b	0b	1c	3c
Dazomet (irrigated)	0b	0b	0b	2b	3b	3b	1b	22b	25b
Dazomet (covered)	0b	0b	0b	0b	0b	0b	0b	1c	2c
Control	11a	19a	23a	18a	33a	34a	298a	260a	263a

[1]Treatment means of the same column followed by the same letter are not significantly different according to the LSD test at P=0.05.

Table 5: Efficacy of fumigants tested against the perennial weeds (Experiment II).

	C. dactylon			*S. halepense*		
Treatments	Stems/8m²					
	Months after treatment					
	1	2	3	1	2	3
Methyl bromide	0b[1]	0b	2b	1b	7b	10b
Metham sodium	0b	1b	7b	0b	0b	1b
Dazomet (irrigated)	0b	8b	14b	1b	8b	8b
Dazomet (covered)	0b	4b	12b	0b	0b	0b
Control	22a	101a	158a	56a	237a	390a

[1]Treatment means of the same column followed by the same letter are not significantly different according to the LSD test at P=0.05.

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INTEGRATED PEST MANAGEMENT AND BIOLOGICAL CONTROL USED IN THE PRODUCTION OF GERBERA IN HUNGARY

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ABSTRACT

Integrated Pest Management (IPM) is possible in gerbera production in Hungary. It is very important to stop using dangerous chemicals in order to encourage the settlement of natural predators from neighbouring unsprayed areas and to improve the predator-pest ratio by using selective chemicals unharmful to predators. The efficacy of plant-protecting agents such as Chess and Confidor are fast decreasing. IPM can lower the risk of resistance developing. Contrary to the practice in the Netherlands, in Hungary it is possible to start a biological control effort in summer by encouraging predators to settle and reducing the cost of crop protection.

KEY WORDS: Biological control, chemical agent, plant-protecting, gerbera, integrated pest management (IPM).

INTRODUCTION

Floratom Ltd is one of the biggest firms in Hungary growing gerbera, tomato and sweet-pepper in South Hungary. It has a 25 000 m^2 (25 ha) protected area. Thermal water is used for heating. Biological control has been successfully adopted in the 22 ha vegetable area in the past ten years. IPM methods have just started recently in the 3 ha gerbera area. Before IPM, a number of pesticides and fungicides were used efficiently including metomil, dimetoat, pymetrozine, methamidofos, abamectine, deltamethrin, bifenthrin and buprofezin. With chemical resistance developing to reduce the efficiency of production, the final change was the introduction of a new pest (*Liriomyza huidobrensis*) which pressed us into an examination of our chemical control methods.

THE EFFICACY OF PLANT-PROTECTING AGENTS

The chemical pest management was changed to integrated pest management (IPM) in the summer. The efficacy of the plant protecting agents against white fly, red spider mite, thrip, aphids, and leafminers is shown in Table 1.

Table 1: The efficiency of plant protecting agents. + = inefficient; ++ = little efficacy; +++ = mild (moderate) efficacy; ++++ = good; +++++ =excellent

Tradename	Generic name	White fly	Red spider	Thrip	Aphids	Leaf miner
3i 58	dimetoat	+	+	++	++++	+
Admiral	pyriproxifen	++++	+	+++	+	+
Andalin	flucycloxuron	+	+++	+	+	+
Apollo	clofentezine	+	+++	+	+	+
Applaud	buprofenzin	+	+	+	+	+
Aztec	triazamaat	+	+	+	++++	+
Chess	pimetrozin	+	+	+	+++++	+
Confidor	imidacoprid	++	+	+++	+++++	+
Decis	deltametrin	+	+	++	++	+

Tradename	Generic name	White fly	Red spider	Thrip	Aphids	Leaf miner
Lannate	metomil	++++	+	+++	+++++	+
Nissorun	hexythiazox	+	+++	+	+	+
Nomolt	teflubenzuron	+++	+	+	+	+
Orthene	acefaat	+	+	+++	++++	+
Pentac	dienochloor	+	++	+	+	+
Pirimor	pirimicarb	+	+	+	+++	+
Sanmite	pyridaben	+++	+++	+	+	+
Talstar	bifenthrin	+	+	++	+	+
Tanaron	metamidofos	+	+	+++	++++	+
Torque	fenbutatinoxid	+	+++	+	+	+
Trigard	cyromazine	+	+	+	+	++++
Unifosz	diclorfosz	+	+	++++	++++	++
Vertimek	ablamectine	+	+++	+++	+	++++

During the changeover period, only chemicals with low persistency were used to prevent high pest numbers. Their low persistency made it possible for natural enemies to settle. During the changeover period, the following plant-protecting agents were used: Cyhexatin, Biosoap, Vertimec, Mach, Admiral, Trigard, Micotal, Addit and Dipel. Since there was a well-established, biologically-balanced tomato area close to the gerbera production area, the natural enemies could settle very fast in the gerbera area. The natural enemies settled in the following sequence: *Eretmocerus eremicus*, *Diglyphus iseae*, *Phytoseiulus persimilis*, *Aphidius colemani*, *Orius laevigatus*, and *Macrolophus caliginosus*.

At the end of August and in September, the cotton moth (*Helicoverpa armigera*) caused the biggest problem. The flowerloss was about 20%. This problem occurred because the moth laid its eggs directly onto the bud and Dipel (*Bacillus thuringiensis* var. *Kurstaki*) was not able to reach the eggs. We plan to introduce *Timalia* (*Alcippe morrisonia*) next year.

In Octobe we tried to reduce the thrip and white fly populations to a low level for planting next spring. Micotal and Addit were used three times and Admiral once. Trigard 1 l/ha was applied for leaf miner control in winter. At the end of February, natural enemies of white fly, red spider mite, thrips, aphids, leaf miner were begun to be introduced (Table 2).

Table 2: Introduction rates of natural enemies in 2001

Pest	Natural enemy	Intr. rate no/m^2	Interval	Frequency	Start
Whitfly	Eretmocerus e.	3	Weekly	Five times	March
	Macrolopus c.	0,5	Weekly	Twice	March
Red spide mite	Phytoseiulus p.	6	Weekly	Twice	February
Thrips	Amblyseius c.	100	Every 4 weeks		February
	Orius l.	0,5	Every 2 weeks	Twice	March
	Hypoaspis a.	100		Once	February
Aphids	Aphidius c.	0,5	Weekly	Three times	February

Pest	Natural enemy	Intr. rate no/m^2	Interval	Frequency	Start
	Rhopalosiphum p.	5/ha	Every 2 weeks		January
	Aphidius e.	0,15	Weekly	Three times	February
Leaf miner	Diglyphus i.	0,1	Weekly	Three times	March

Macrolophus population was so large in June that it endangered the flowers and a drip Imidakloprid treatment was applied in order to prevent significant flower loss.

CONCLUSIONS

The only disadvantage of biological control so far noted has been the occurrence of sugar disease, a disorder known only from literature and not from the everyday practice. This is a little-known disease which destroys the plant only after the fruit fly has bred. Fruit fly is a vector and a catalyst in the development of the infection. A sweet section flows out from the picked flower stem and a bacterium species multiplies in this sweet fluid. This brown and white sweet-smelling, foamy, mass appears on the surface and the fruit fly breeds on this mass.

The most important activities to control sugar disease in gerbera are to reduce root pressure (early stop and late start of the irrigation, adjust the vegetative-generative balance early in the life of the young plant), to trap fruit fly with fermenting material, and to remove affected plants.

METHYL BROMIDE ALTERNATIVES FOR CUT-FLOWER PRODUCTION IN CHIPIONA

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ABSTRACT

Cumulative yields of carnation cultivars Erika and Master over an 18 and 13 month period, respectively, in a greenhouse infested with *Fusarium oxysporum* f.sp. *dianthi* and with different soil disinfestation treatments showed that some of the treatments were possible alternatives to methyl bromide (MB). Dichloropropene + chloropicrin, and metham-sodium, were the fumigants providing yields similar to MB. Steam for 2.5 h was also highly effective. The application technique determined the success of these treatments. In order to improve the effectiveness of alternative fumigant treatments and, more importantly to get consistent results, a careful application technique in combination with other control methods was strongly recommended.

Key words: carnation, Fusarium vascular wilt, soil fumigation, soil steaming, soil solarization

INTRODUCTION

Due to methyl bromide (MB) being phased, there is a need to find efficient alternatives to control soilborne pathogens in carnations grown on the NW coast of Cadiz and Low Guadalquivir crop areas. Environmental concerns related to ozone layer depletion obligates avoidance in the use of MB which has been easily applied for many years.

This work aimed to compare carnation yields in plots naturally infested with *Fusarium oxysporum f. sp. dianthi* (Fod) which were treated with several desinfestation treatments, including standard treatments of MB, in an effort to find alternatives to MB.

MATERIAL AND METHODS

Two greenhouse experiments (Exp. 1 and 2) were established in 1998 and 2000 that were known to have infested soil which subsequently received the treatments indicated in Table 1 in June of each of these years. Soil amendment consisted of cow manure applied before the treatment applications in 1998, and disinfected sheep manure applied after the treatments in 2000. The same greenhouse, infested with Fod and located in CIFA Chipiona, Cádiz, was used for both experiments. Carnation cvs. Erika (highly susceptible to Fod) and Master (susceptible to Fod) were planted in early July 1998 and 2000, respectively.

Except for MB and the steam application, the treatments tested in Exp. 1 were applied by means of a specific localized irrigation system. A precision injection pump was used for the chemical applications conducted in Exp. 2. The experimental plots had 3 and 1 raised bed in Exp. 1 and 2, respectively, but the same area (5 m, with 124 plants) of the central bed was used in both cases for yield data. These were collected twice each week. The experimental design was 4 completely randomised blocks.

Table 1. Soil treatments applied in infested greenhouse previous to carnation planting

Treatments	Experiment 1(1998/2000)	Experiment 2 (2000/2002)
A	Untreated control	Untreated control
B	MB 98% at 100 g/m^2 + PE 50µm	MB 98% at 30 g/m^2 + VIF
C	MB 98% at 20 g/m^2 + VIF	Metham-Na 40% at 100 g/m^2 + VIF Solarization
D	Dichloropropene 81.9% + Chloropicrin 65.5%, at 40 g/m^2 + PE 50µm	Solarization with CP-129 film
E	Steam (2 h)	Dichloropropene 81.9 % + Chloropicrin 46.5% at 40 ml/m^2 + VIF Solarization
F	Metham-Na 40% + Dichloropropene 95% at 80 + 40 ml/m^2 + PE 50µm	Steam (2.5 h)
G	Metham-Na 40% + Aldicarb 10% at 80 ml + 10 g/m^2 + PE 50µm	Poultry manure at 5 kg/m^2 + CP-129 Solarization

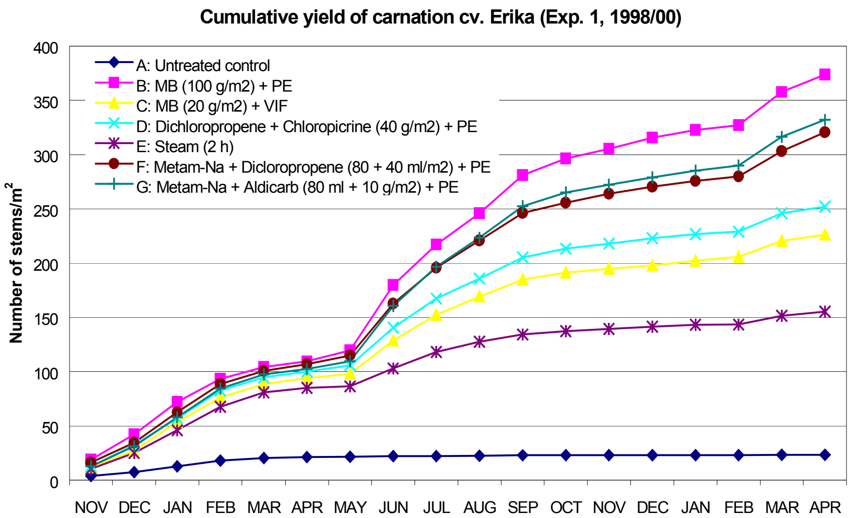
RESULTS

Both experiments were harvested from November and a sharp increase in yield was observed in June. Insignificant yield was obtained from untreated plots (Figures 1 and 2).

Experiment 1 (1998 to 2000)

Maximum yield corresponded to the treatments of MB (100 g/m^2) which reached 374 stems/m^2 for the duration of the 18 months of harvest. A reduction of 11-15% final yield corresponded to the treatments of metam-sodium + Aldicarb and metam-sodium + Dichloropropene (1,3-D), and 33% was the yield reduction for the treatment of 1,3-D + chloropicrin. A lower yield was obtained with MB (20g/m^2 + VIF treatment), and maximum yield reduction (59%) was observed in the steam treated plots which had a cumulative production of 155 stems/m^2 only (Figure 1).

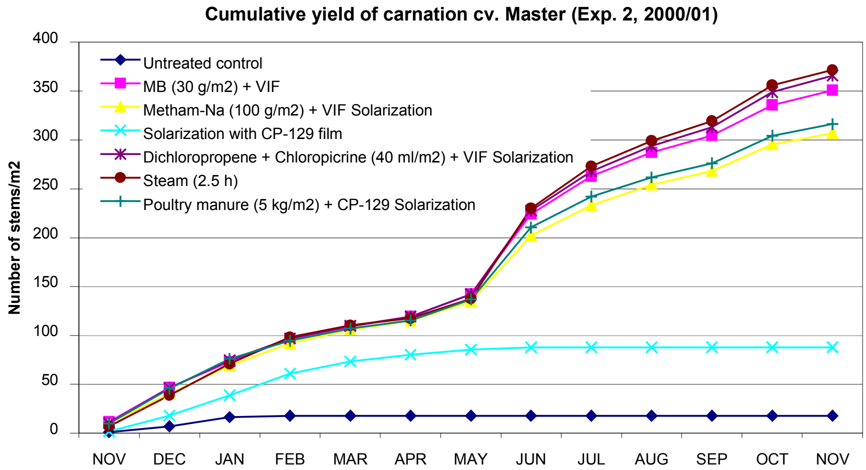
Figure 1: Cumulative yield of carnation cv. Erika (Exp. 1, 1998/2000)



Experiment 2 (2000-2001)

The yields harvested over a 13 month period were slightly more than 350 stem/m^2 for the treatments of steam, 1,3-D + chloropicrin, and MB30 + VIF. The vigour of the plants was superior in the first two treatments. A reduction of 10-13% from those values was observed for the treatments of metam-sodium + VIF and poultry manure + CP-129 (Figure 2).

Figure 2: Cumulative yield of carnation cv. Erika (Exp. 2, 2001/2002)



DISCUSSION AND CONCLUSIONS

Our results showed that there were two kinds of alternative treatments to MB. Firstly, the steam treatment of soil, and secondly, the use of other fumigants based on metam-sodium or chloropicrin, both well know for their fungicidal properties. In all of these treatments, a lack of consistency appeared in the results of Exp. 1 and 2. This could be explained by the different requirements in the application technique that must be adapted to the specific formulations in the case of the fumigants and to a suitable duration for the steam treatment in order to achieve temperatures lethal to inoculum in lower layers of the soil. Implementation of this treatment presents, however, difficulties in the cropping systems used in the area and also there are economic disadvantages. In order to improve the effectiveness of alternative fumigant treatments and, more importantly to get consistent results, a careful application technique and combination with other control methods, such as the use of less susceptible carnation cultivars, is strongly recommended.

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CLOSED SOILLESS TECHNIQUES FOR CUT-FLOWER PRODUCTION AS AN ALTERNATIVE TO METHYL BROMIDE IN MEDITERRANEAN CONDITIONS

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ABSTRACT

Two experiments were carried out using carnation and gerbera to demonstrate the technical and economical viability of using closed soilless systems under Mediterranean conditions to eliminate the use of MB in cut flower crops. High yield, high-quality cut-flowers and a good economic rate of return were obtained when carnation and gerbera were grown using soilless cultivation.

Keywords: Soilless cultures, closed systems, carnation, gerbera

INTRODUCTION

Conventional intensive horticulture in the European Community, and specially along the Mediterranean shores, has contributed to the pollution of the environment (Ramos, 1993; Baille, 1993; López-Gálvez and Naredo, 1996; Walle and Sevenster, 1998). Intensive horticulture's use of pesticides, plastics and nutrient leachates is an agricultural activity that contaminates the environment by polluting the soil, the underground water reservoirs and the atmosphere.

One possibility is to cultivate by substituting the use of conventional natural resources such as water, fertilizers, petroleum derivates such as fuel, pesticides, fumigants (such as methyl bromide (MB)), plastics and others, with technological inputs (Marfà 1994). Soilless techniques do not result in a higher energy consumption than the conventional techniques used in horticulture because soilless techniques eliminate the use of soil fumigants such as MB which can destroy the ozone layer (Rodríguez-Kabana 1996), and they allow the use of plastics and other energy-consuming products more efficiently.

The open soilless techniques result in a lot of leachates accumulating in the ground. As such, the sustainability of the open soilless techniques is not clear since a high quantity of leachates is wasted to assure a steady level of salt in the root zone. For instance, in a tomato crop grown on rockwool during winter in Almeria (southeast of Spain), the estimated leachate volume was 1250 $m^3.ha^{-1}$ (Ramos 1993). For a rose crop grown on perlite in the French Mediterranean coast, the estimated leachate was 2000 $m^3.ha^{-1}.year^{-1}$ (Baille 1993).

To overcome these problems, closed soilless techniques which involves recycling nutrient solutions must be used. In the Mediterranean countries, the open soilless techniques were recently introduced and the technical and agricultural limit for recycling is the water quality.

In order to show the technical and economical viability of closed soilless systems under Mediterranean conditions to potential users, some experiments on a commercial agriculture scale were conducted at the Cabrils Research Center of IRTA on carnation and gerbera, two important crops in the Mediterranean floriculture industry.

MATERIAL AND METHODS

Grow bags filled with expanded perlite were used for growing gerbera and carnation in a 300 m^2 glasshouse. A closed soilless system was used to collect, filtrate, desinfect, return to closed system and adjust the leachates to their original composition automatically. The automatic equipment prepared nutrient solutions with five concentrate solutions and nitric acid. The equipment reconstituted the nutrient solution automatically. The desinfection unit consisted of two filters and a UV lamp. The watering frequency was established automatically using a radiometric sensor and an electro-lysimeter, acting simultaneously and complementarily.

In the first year, carnation was grown using this system. The density of plants was 17.7 m^{-2} and the crop was grown corresponding to a late planting. The average leachate fraction during the growing period was 29%. The electrical conductivity (EC) of the water used was 1 $dS.m^{-1}$. In the second year gerbera was grown. The density of plants was 5.75 m^{-2}. The average leachate fraction was 26.5%. The average EC of the water was 0.6 $dS\text{-}m^{-1}$.

RESULTS

In the carnation crop, the total water dose was 990 $L.m^{-2}$, the total volume of leachate was 208 $L.m^{-2}$ and the volume of leachate wasted was only 20 $L.m^{-2}$. In the gerbera crop, the total water dose was 795 $L.m^{-2}$, the total volume of leachate was 211 $L.m^{-2}$ and the volume of leachate wasted was zero.

The nitrate nutrient balance was 1915 and 686 $kg.ha^{-1}$ in carnation and gerbera, respectively; 691 and 319 $kg.ha^{-1}$ were recirculated; and 41.5 and zero $kg.ha^{-1}$ were wasted. The phosphate nutrient balance was 626 and 278 $kg.ha^{-1}$ given to carnation and gerbera, respectively; 226 and 127 $kg.ha^{-1}$ were recirculated; and 27 and zero $kg.ha^{-1}$ were wasted. The potassium nutrient balance was 3134 and 1704 $kg.ha^{-1}$ given to carnation and gerbera, respectively; 924 and 652 $kg.ha^{-1}$ were recirculated; and 2.4 and zero $kg.ha^{-1}$ were wasted. The yield obtained in the carnation crop was 9.7 flowers per plant which is the same as 172 m^{-2} and for gerbera the yield obtained was 37 flowers per plant which is the same as 213 m^{-2}. The calculated internal rent rate of the crops was 20% and the net actual value was € 74.12 per m^2.

CONCLUSIONS

The closed soilless technique in Mediterranean conditions for growing carnation and gerbera:

- Used average water quantity which resulted in high yield, high-quality cut-flowers and produced a high rate of return for the grower;
- Required no large technical preparation;
- Recycled leachates automatically and efficiently disinfected them;
- Obtained very high water and nutrient-use efficiencies; and
- Eliminated completely the use of MB.

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NON-CHEMICAL ALTERNATIVES USED IN THE USA ON HORTICULTURAL CROPS

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ABSTRACT

A variety of non-chemical alternatives to methyl bromide (MB) fumigation of soil for horticultural crop production have been researched in the USA. Non-chemical alternatives are highly desirable but difficult to implement to reproduce the benefits normally obtained by preplant fumigation of soil in strawberry production. Production of pathogen-free, high-quality planting materials using steam and other physical methods of soil disinfestation have not been perfected for large-scale runner plant production. Genetic resistance or tolerance to specific soilborne pathogens is important and can be improved. While crop rotation improve strawberry yields and in some cases reduced soilborne disease, the high cost of land and infrastructure for strawberry production precludes rotation as an option. Solarization, biofumigation and/or organic soil amendments have been tested but have have not been successful. Soil amendments must be used at relatively high rates for effects to be significant, and the results have been variable between years. Beneficial microorganisms to enhance strawberry production have produced highly variable results. In general, further research is needed to further optimize and integrate nonchemical alternatives to MB.

Keywords: Non-chemical alternatives, steam, genetic resistance, crop rotation, solarisation, biofumigation, soil amendments, beneficial microorganisms, strawberries

INTRODUCTION

A variety of non-chemical alternatives to methyl bromide (MB) fumigation of soil for horticultural crop production have been researched in the USA. Unfortunately, it is generally difficult to reproduce the high levels of soilborne pathogen control, weed control, and yield stimulation normally obtained in horticultural systems with MB and other soil fumigants by non-chemical methods. This is especially the case for high-input, high-value crops such as strawberries, tomatoes, peppers and flowers grown annually on the same ground. As a result, non-chemical methods have generally not replaced soil fumigation in most large-scale horticultural crops where MB has been used in the USA. While this case study will focus on strawberry production in California, many of the conclusions apply to other horticultural crops. Replant disorders of woody perennials, however, may be somewhat different and will not be considered specifically.

An important measure in horticultural crop production is to start with pathogen-free, high-quality planting materials. This is achieved to a large extent in strawberry by producing runner plants in fumigated nursery fields. Plug or container plants can be produced using artificial or heat-treated substrates as an alternative, but it will be difficult, if not impossible, to meet the full demand for strawberry transplants by these methods. Steam and other physical methods of soil disinfestation have not been perfected for large-scale runner plant production, and soil fumigation with MB or chemical alternatives is likely to be needed indefinitely for some phases of strawberry nursery production.

Genetic resistance or tolerance to specific soilborne pathogens can be important. For example, some California strawberry varieties have helpful levels of tolerance to *Phytophthora* root and crown rots (Browne *et al.* 2001). None of the current varieties, however, has sufficient tolerance to Verticillium wilt (Duniway et al. 2001). Equally important, the general yield response of strawberry to soil fumigation involves reductions in a number of other fungi damaging to roots (Duniway *et al.* 1999; Martin 2001). While California varieties differ in their responses to these fungi and to nonfumigated soils (Martin 2001), there is considerable debate about the prospects for developing strawberry varieties that can achieve the current high yield potential and berry quality without soil fumigation. There is little doubt, however, that genetic tolerance to specific soilborne pathogens can be improved.

Crop rotation can improve strawberry yields and in some cases may reduce soilborne diseases. For example, one-year rotations out of strawberry with rye or two crops of broccoli improved subsequent strawberry yields on nonfumigated soil by 18-44% (Duniway *et al.* 1999, 2000). Fumigation of the same ground, however, approximately doubled yield. Broccoli rotation and incorporation is reported to reduce Verticillium wilt in subsequent crops, but results obtained so far in strawberry are variable (Duniway *et al.* 1999, 2000). While crop rotation is highly desirable, the high cost of land and infrastructure for strawberry production in coastal regions of California usually leads to annual plantings of strawberries on the same ground.

A variety of nonchemical soil treatments have been tried for strawberries in California, including solarization, biofumigation and/or organic soil amendments. Because of seasonal coastal fogs, only a small fraction of the acreage used for strawberry production in California has a climate that is suitable for solarization at the time it would be needed. A variety of soil amendments have been used with mixed results. Composts are used routinely in organic production (Bull 1999), but they have not generally given significant yield increases or disease suppression when applied in conventional strawberry production systems (Duniway *et al.* 1999). High-nitrogen organic amendments, such as blood meal, can reduce Verticillium wilt significantly, but can also cause phytotoxicity (Duniway *et al.* 1999, 2000, 2001). Furthermore, soil amendments must be used at relatively high rates for effects to be significant, and the results have been variable between years (e.g. Duniway *et al.* 2000, 2001).

There is considerable interest in using beneficial microorganisms to enhance strawberry production in California. A variety of fungi and bacteria from commercial sources have been applied to bare-root transplants and/or through drip irrigation systems. While some of these inoculations increased yield in nonfumigated soils, more beneficial results were sometimes obtained in soil fumigated with chloropicrin (Duniway *et al.* 2000, 2001; Eayre 2001). In addition, some rhizobacteria isolated from strawberries grown in fumigated soils have been found to increase the growth and/or yield of strawberries grown in nonfumigated soil or soil treated with a low rate of chloropicrin (Duniway *et al.* 2000, 2001; Martin 2001). Inoculations of strawberry with mycorrhizae have given inconsistent results (Bull 1999). Unfortunately, the results obtained with biological controls or beneficial microorganisms to date have been highly variable and more research is needed to optimize their potential utility in strawberry production.

From environmental or social points of view, nonchemical alternatives to MB are highly desirable. From an agricultural point of view, however, they are difficult to implement to effectively reproduce the benefits normally obtained by preplant fumigation of soil in strawberry production. Obviously, more research is needed to further optimize and integrate nonchemical alternatives to MB. Strawberry production in California, however, is already a highly integrated and complex farming system using IPM strategies extensively, and it is unlikely that current levels of production can be achieved using only nonchemical alternatives to MB. It is more likely that some of the nonchemical alternatives can be used to augment chemical alternatives applied at lower rates by more efficient methods.

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NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USED IN MEXICO

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ABSTRACT

Watermelon exports from Mexico were valued at US$7.0 million in 2000. MB has been used for watermelon production in Mexico since 1989 to control mainly root-knot nematode (*Meloidogyne* spp), soil-borne fungi, weeds. In 1998, approximately 435 tonnes of methyl bromide (MB) were used to fumigate 96 ha of watermelon seedbeds. As an alternative, solarisation seed trays, manure and growth promotors can substitute for MB. Seedlings were coated with growth promotor just before planting into a hole filed with chicken, cow or goat manure. Conventional insecticidal or fungicide was used to control plant pests. Weeds were manually eliminated throughout the growth season and one application of chemical fertilizer was applied manually or via the drip irrigation system. The alternative advanced the harvest and increased yield by about 30%. This alternative could also be used by cucurbit or tomato growers in Mexico and many countries with similar growing conditions. This system has eliminated the use of MB and plastic mulch in areas where weed and water problems are not limiting factors.

Keywords: watermelon, Mexico, methyl bromide, alternative, growth promotor, solarization, manure

INTRODUCTION

The total production value of watermelons in Mexico was close to US$232 million in 2000 (1,069,057t). About 28% of the crop was exported, mainly to the United States, bringing a return of US$7 million. The case study focuses on production in the Rio Balsas watershell region and the Mixtec region both located in the south east of the state of Puebla and East of the State of Guerrero. Both regions are characterized by rivers, a river basin, small valleys with wells and irrigation systems, hills and mountains, and slight to steep slopes with gradients from 20-60 degrees. It is typical subtropical dry region with altitudes in the range of 500 to 1800 m above sea level.

Crop production characteristics

Generally in Mexico watermelon is grown by highly qualified grower that produces seedlings in a greenhouse or covered area before they are transplanted to the field. Normally the substrate used for seedlings is fumigated or steam sterilized. Some growers in the field use plastic mulch under drip irrigation or other type of irrigation. A great number of growers still prefer direct sowing and occasionally non-fumigant nematicides application because the relative high initial investment to adopt an alternative system. This implies technical advice, training, setting up drip irrigation system and plastic mulch.

In the Mixtec and Balsas regions watermelon is a traditional crop of small irrigated areas (1-3 ha) located around the rivers and land with small scale irrigation infrastructure, wheels and reservoir dams. Watermelon is grown on 2000 ha mostly sandy soils in about 800 family-run farms. There are a few commercial enterprises ranging in size from 10-20 ha.

Use of methyl bromide

MB has been used for watermelon production in Mexico since 1989 to control nematodes, mainly root-knot (*Meloidogyne* spp), soil-borne fungi, weeds. In the past, most growers who had difficulties controlling soil-borne pests with pesticides turned to MB because they found it more effective. It is primarily used to fumigate soil for seedlings in greenhouses and may also be used for partially protected seed-beds in the fields. In 1998 an area of seed-beds close to 96 ha was fumigated for watermelon at 454g/m^2 rate.

Commercial use of alternative

Starting in 2000, 18 watermelon growers from both the Mixtec and Rio Balsas regions started to use solarised substrate (primarly coconut dust mixed with organic soil) for seed trays.

Seedlings are transplanted in the open field (3000 –3500 plants/ha) in a hole with 300-350 g of manure. During the first week the seedlings are treated with Horticplus® or endospore® (both biocontrol-plant growth promoters) in the foliage or through the irrigation system. The roots may be infected but at the end damage is acceptable since yield is marginal reduced. This system costs less than the production using MB and it is an excellent option for growers that cannot establish plastic mulch with drip irrigation in their production unit due to lack of capital. Plastic mulch can only be used in one season and their uneven land makes it difficult to lay down plastic sheets.

Typically, the following materials are required: Plastic sheets for solarisation of substrate; Substrate (coconut dust or volcanic grave mixed with organic soil); Seed-trays (60-77 cells) or 250cc polyurethane cups; Manure from chickens, cows or goats; Seeds coated with antifungal agents; Biocontrol-plant growth promoters.

Seeds are imported (generally from the USA) coated with antifungal treatment. No chemical treatment for substrate strerilisation is needed due to solarisation with white plastic sheets. Seeds are allowed to germinate in conventional seed-trays or polyurethane cups.

Conventional insecticide or fungicide is use to control top plant pests if necessary. Weeds are manually eliminated throughout the growth season and one application of chemical fertilizer is applied manually or via the drip irrigation system during the flowering period.

Yield and Performance of Alternative

The conventional MB system used for watermelon in the Balsas region gives an average yield of 23 tonns/ha. Using the alternative system yield increase to 35 tonnes/ha. The advantages of the system are given in Table 1, and the yield information in Table 2 when compared with MB. The alternative system prevented nematode and soil borne pathogen attack during the first 20-30 d after transplanting.

Table 1: Comparison of performance and benefits of alternative system and MB

SOLARIZATION SEED TRAYS, MANURE AND BIOCONTROL-GROWTH PROMOTERS	MB SYSTEM
Plants grow stronger and more uniform	Plants tend to be weaker and less uniform
High quality watermelons	Lower quality plants
Earlier harvest date	Requires an extra month growing period
Requires less chemical pesticides	Requires more chemical pesticides
Yield of 35 t/ha	Lower yield of 23t/ha
No significant worker safety issues	Worker safety concerns because MB is a toxic gas
Operation cost is cheaper over 3 years, but needs an initial investment to set up the system	Operation cost is higher, but initial capital investment is not required

This protected the roots during the most vulnerable plant stage. In addition, it improved top and root growth of watermelons plants giving a better and faster growth and advancing the harvest an average of 20 days.

Table 2: Comparison of watermelon yields using MB and Alternative system

Farm size	Yield using alternative	Yield using MB (t/ha)
1-3ha	35	23

Limitation of the alternative system is the lack of technical support to trainee rural growers to adopt the system. Intensive efforts are in progress to fill this gap seeking support from any government or non government agency. This alternative system for controlling soil-borne pests does not require regulatory approval because it does not use toxic materials. The yield increase and shorter growing period allows growers to arrive earlier in the market and to sell the product at higher prices.

Comparative costs between MB system and alternative system are summarized in Table 3. The alternative saves costs associated with the use of machinery, fertilizer and chemical pesticides. However the extra yield and the higher prices obtained at the beginning of the season make it a highly attractive system for growers. In addition using manure from rural activities is a better way to recycle natural organic waste. All the items (plastic sheets, seed trays, horticplus, endospore) can be obtained in major cities close to the regions.

This multi-tactic alternative system could also be used by cucurbit or tomato growers in Mexico and many countries with similar growing conditions. This system has eliminated the use of MB and plastic mulch in areas where weed and water problems are not limiting factors.

Table 3: Costs of using MB and alternative system (solarization of substrate, seed trays, manure, biocontrol) for watermelon production in Mixtec and Balsas regions.

ITEM	ALTERNATIVE SYSTEM US$/HA	MB SYSTEM US$/HA
Machinary	0	120
Labor	150	112
Seed	30	30
Fertilizer	50	230
Chemical pest control	500	620
Plastic sheet	20	20
Seed trays	30	30
Substrate	30	30
Watering	20	20
Fuel for water pump	70	70
	1020	1282

Source: Marban-M and Venegas-Bustamante, 1999.

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NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE IN GREENHOUSE-GROWN SWEET PEPPER IN SPAIN

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ABSTRACT

Sweet pepper cultivation in Campo Cartagena (Murcia) and Pilar de la Horadada (Alicante) is of great socio-economical importance as about 180,000 tonnes per year are grown on more than 1,880 ha. Trials tested rhizobacterium inoculated seedlings, biofumigation with solarization with different materials, rate and timing of application; grafted rootstocks tolerant to *P. Capsici* and *M. Incognita*; and soilless culture with organic substrates coming from the agrifood industry. Soilless cultivation, biofumigation with solarization and grafted plants, alone or combined, were considered alternatives to MB. The choice of one or other depended on the area and productive cycle, the degree of specialisation, the tehnical skills of growers and technicians, the level of technological development and the availability of sufficient manure or biofumigation material. The cost of non-chemical alternatives is likely to be similar to, or lower than, chemical alternatives.

Keywords: Biofumigation, grafting, sweet pepper, non-chemical alternatives, methyl bromide

INTRODUCTION

This paper reports on non-chemical alternatives to methyl bromide (MB) in sweet pepper grown in greenhouses in Spain, and in particular research carried out in Campo Cartagena (Murcia) and Pilar de la Horadada (Alicante), classified by the European Union as less favoured areas. In this area, sweet pepper is of great socio-economical importance as about 180,000 tonnes per year are grown on more than 1,880 ha. The crop is fragmented into many small family holdings with an average land area of 1.6 ha.

Sweet pepper cultivation started in 1973 and currently the crop can be considered as a monoculture in this area. The crop starts with seeding in nurseries in October, soil transplant in November-December and harvest from March to September-October. The phytosanitary problem in soil used for pepper cultivation is due to *Phytophthora capsici*, *Meloidogyne incognita* and other problems of unknown nature caused by repeated cultivation of crops on the same land and a resultant decline in profitability. Since the beginning of cultivation, soil disinfection has been the usual practice. Disinfections were first made with metam sodium followed by the use of methyl bromide (MB) in 1985. The phase out schedule for MB reduction and elimination provokes an uncertain situation and uneasiness in the pepper production sector.

METHODS

The Federación de Cooperativas Agrarias de Murcia (FECOAM) joined a programme with the Consejería de Agricultura, Agua y Medio Ambiente Centro de Investigación y Desarrollo Agroalimentario (CIDA) in the search for alternatives to MB in greenhouse pepper crop.

The importance of a production system that is respectful of the environment, such as the case with Integrated Pest Management Production (1,100 ha) and organic agriculture (32 ha), as well as the growers request for using clean technologies, made it necessary to direct research toward non-chemical alternatives that might resolve the phytopathological problems. One of these alternatives was the use of rhizobacterium inoculated seedlings, biofumigation with solarization with different materials, and rate and date of application; grafted, tolerant rootstocks to *P. Capsici* and *M. Incognita*; and soilless culture with organic substrates coming from the agrifood industry.

DISCUSSION AND CONCLUSIONS

From trials carried out in the last three growing seasons in the Campo Cartagena greenhouses the following conclusions may be drawn:

1) Rhizobacterium applied to seedlings in nurseries did not give as good results as the usual MB disinfections.

2) Biofumigation with solarization was effective in controlling *P. capsici* and less effective in controlling *M. Incognita* than MB. However, neither yield nor plant development reduction were significant. Repeated applications over consecutive years led to an increase of pathogen control, weeds, yield and soil physico-chemical properties. Fresh sheep manure (4-7 kg/m^2) with chicken manure (2-3 kg/m^2) used for biofumigation was a limited resource that the local market was unable to provide. The best results were obtained when biofumigation was made at the end of September at the latest, although, at that time, the growing season was still ongoing. It was interesting to note that the incorporation of plant remains accounted for over 7 kg/m^2 of fresh biomass and helped to make up for the limited availability of sheep and chicken manure. The cost of the whole disinfection process was 0.35 €/m^2. Currently, more than 40 ha of pepper commercial greenhouses use this disinfection method.

3) Grafted plants produced good control of *P. capsici* and *M. Incognita*. There are also firms that focus their research on developing tolerant or resistant plants to this pathogens. However, the technique was expensive and increased seedling cost to over 0,30 € per plant (0,75 €/m^2) which led to a final price of approximately 0,51 € per plant. Grafted pepper plants have not been used commercially, contrary to the case of other vegetables grown in the area such as watermelon or tomato. When the technique is affordable, it would be interesting to combine it with other soil management methods to reduce or mitigate the soil exhaustion. The producion sector is very optimistic about this technique as it is a biological solution to solve soil problems.

4) Soilless cultivation. It has been trialled with organic material, coconut fibre and agrofood industry subproducts such as rice husk and crushed almond shells. On the other hand there are materials from inorganic origin, such as perlite and rockwool, all of them giving successful results and higher profits than MB, when managed properly. However, a high technological investment is needed to increase the knowledge of growers and technicians. Moreover, soilless cultivation in pepper crops has yet to be calibrated to our agroclimatic characteristics. Currently, soilless culture accounts for less than 40 ha.

To conclude, we can say that the soilless cultivation, biofumigation with solarization and grafted plants, alone or combined, are alternatives to MB. The choice of one or other depends on different factors such as the area and productive cycle, the degree of specialisation, the tehnical skills of growers and technicians, the level of technological development and the availability of sufficient manure or biofumigation material. In this latter case, apart from offering a productivity guarantee, a product of high quality and healthy with no environmental cost, the cost of non-chemical alternatives will be similar to, or lower than, chemical alternatives.

GRAFTING AS A NON-CHEMICAL ALTERNATIVE TO METHYL BROMIDE FOR TOMATOES IN SPAIN

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ABSTRACT

Grafted tomato has been known for a long time but has only recently been expanded into cultivars of *Cherry* and *Marmande* types as a way of protecting against soil-borne diseases or against 'collapse', a non-well known disease typical of winter-producing tomato crops. Grafted tomato plants provided resistance to vascular diseases (*Fusarium* and *Verticilium*), and nematodes, even in varieties that have no resistance. Grafting onto interspecific rootstocks (*L. esculentum x L. hirsutum*) improved plant vigour and led to crop two-branch plants. The same yields were obtained with half the plant density, and moreover, without reducing the quality of the fruit. Grafted tomato can therefore be considered an alternative to the use of methyl bromide for tomato production in Spain.

Keywords: tomato, grafted, Fusarium, Verticilium, methyl bromide, alternative

INTRODUCTION

Grafted watermelon, using rootstocks resistant to soil-borne diseases, has expanded considerably in Spain over the past 10 years. Nowadays, it is hard to find ungrafted plants in the most important production areas, both in greenhouses and in the open air. Grafting is a non-polluting technique. Grafting onto cucurbit rootstocks (*Cucurbita maxima* x *Cucurbita moschata*) improved the vigour of watermelon plants, made them completely resistant to *Fusarium oxixporum f. sp. niveum* and tolerant to a broad range of pathogens. As a consequence of the yield and production security obtained using grafted plants, grafting in watermelon has proved cost-effective and eliminated the need for soil disinfection with methyl bromide (MB) even before its prohibition.

In melon, grafting makes plants resistant to *Fusarium oxisporum f. sp. melonis* and to *Melon Necrotic Spot Virus* (MNSV). The usual rootstocks are also tolerant to *Monosporascus cannoballus*. There are some affinity problems with Spanish-type cultivars and an increase in fruit size in other cultivars of Galia and Cantaloup types. These problems have slowed the expansion of this technique in melon production.

In tomato, grafting has been known for a long time but it has only recently been expanded into cultivars of *Cherry* and *Marmande* types as a way of protecting against soil-borne diseases or against 'collapse', a non-well known disease typical of winter-producing tomato crops.

COMPARISON OF ROOTSTOCKS IN DIFFERENT TOMATO CULTIVARS

Two experiments were carried out in Alginet (Valencia, Spain) in a tunnel covered with anti-thrips net, and in Paiporta (Valencia, Spain), in a greenhouse covered with both anti-thrips net and plastic film. Tomatoes were planted on 4 August 2000 and 26 January 2001 respectively.

The same rootstocks were used in both experiments: 'Brigeor' (*Lycopersicon esculentum x Lycopersicon hirsutum*) (KNVF_2Fr) and 'SC-6301' (*Lycopersicon esculentum*) (NVF_2Fr). In Alginet, the cultivars 'Valenciano' and 'Bond' (VF_2N) were used. In Paiporta, 'Bond' (VF_2N) and 'Raf' (F) were used.

In Alginet, the highest yields were obtained in grafted plants of both cultivars, although the differences between those and control plants were only significant in plants grafted on 'SC-6301'.

Yields were also significantly (99%) higher in plants of ‘Bond’ than in plants of ‘Valenciano’. At the end of the crop, 40% of ungrafted ‘Valenciano’ plants had died, with the root system destroyed or severely damaged by nematodes, while all grafted plants of the same cultivar and either grafted or ungrafted plants of cultivar ‘Bond’ were alive.

Table 1: Total tomato yield and mortality of plants. Alginet 2000.

	YIELD (Kg/m^2)			DEAD PLANTS (%)	
Root stock	**Bond**	**Valenciano**	**Average**	**Bond**	**Valenciano**
Brigeor	6.22	4.27	5.25 ab	0	0
SC-6301	6.37	5.08	5.72 a	0	0
Non grafted	5.50	3.17	4.33 b	0	40
	6.03 a	4.17 b			

Similar results were observed in Paiporta. Both cultivars (‘Raf’ and ‘Bond’) grafted onto both rootstocks or ungrafted plants of ‘Bond’, were resistant to nematodes and produced higher yields than ungrafted plants of ‘Raf’.

Table 1: Total tomato yield and root-knot index. Paiporta 2001.

	YIELD (Kg/m^2)			ROOT-KNOT INDEX		
Rootstock	**RAF**	**Bond**	**Average**	**RAF**	**Bond**	**Average**
Brigeor	11.95	16.61	14.28	0.71	0.75	0.73
SC-6301	11.24	14.66	12.95	0.50	0.25	0.37
Non grafted	4.70	15.80	10.25	3.91	1.41	2.66
	9.97 b	15.35 a		1.71	0.80	

COMPARISON OF PLANT DENSITIES AND TRAINING METHODS USING GRAFTED TOMATO PLANTS

This experiment was conducted in Paiporta. Plants of cultivar ‘Raf’ grafted onto the rootstock ‘Brigeor’ were planted on 26 January 2001 in a greenhouse covered with anti-thrips net and plastic film. Two branch densities were compared, obtained as follows: 2.86 branches/;m^2; 2.86 plants/m^2, 1 branch/plant; 1.43 plants/m^2, 2 branch/plant; 2.29 branches/m^2; 2.29 plants/m^2, 1 branch/plant; and 1.14 plant /m^2, 2 branch/plant.

In this experiment, no significant differences were observed between plant densities or training methods, and therefore it was possible to obtain the same yields both reducing plant density and training plants in two branches.

TABLE 3. Tomato yield (Kg/m^2 and Kg/plant) with differents plant densities and training methods. Paiporta 2001.

	Kg/m^2			Kg/plant		
	One branch per plant	**Two branches per plant**	**Average**	**One branch per plant**	**Two branches per plant**	**Average**
2.86 branches/m^2	16.61	15.93	16.27	5.81	11.15	8.48
2.29 branches/m^2	14.98	13.80	14.39	6.55	12.08	9.31
	15.79 a	14.86 a		6.18	11.61	

CONCLUSIONS

Grafted tomato plants provided resistance to vascular diseases (*Fusarium* and *Verticilium*), and nematodes, even in those varieties that have no resistance. Grafting onto interspecific rootstocks (*L. esculentum x L. hirsutum*) improved plant vigour and led to crop two-branch plants. The same yields were obtained with half the plant density, and moreover, without reducing the quality of the fruit.

THE ECONOMIC IMPACT OF THE PHASE OUT OF METHYL BROMIDE ON HORTICULTURAL PRODUCERS IN HUNGARY

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ABSTRACT

Horticulture and mainly vegetable growing is a very important sector of the Hungarian Agriculture especially if export is considered. MB is used against soil borne pathogens, mainly nematodes under glasshouses and heated plastic tunnels, and in few cases under non heated plastic tunnels for vegetable growing. It has been registered since the mid 1980's. The tobacco industry was also using MB until 1999 when they converted to floating bed technology and phased out their use of MB. The future for protected vegetable production, the use of MB and preparations for eliminating its use are described.

Keywords: economic impact, phase out, geothermal energy, Hungary.

INTRODUCTION

Árpád Co is one of the top Hungarian agriculture companies. Árpád as a Vegetable Growing Co-operative was founded in 1960. It was first involved with open-air crops and later with crops grown under glass and plastic. Today Árpád is no longer a Coop because of political and economical reasons. The company changed to an Incorporated Share Company in 1999, with a founding capital of 3 Billion HUF which is about US$10 million.

Szentes and the surrounding area has a tradition in vegetable production going back for centuries. Gardners from the present Bulgaria immigrated to Hungary in 18th century and established a new method of vegetable production with intensive irrigation between the rows. They also brought with them their new types of vegetables not grown in Hungary before. These gardeners delivered their products not only in towns in Hungary but deliveries went as far as Vienna.

The region has good soil quality. From the rivers and irrigation canals in the nearby good quality water could be gained for irrigation. There are more than 2 050 sunshine hours each year. A special condition of the area is geothermal energy. The vegetables have been grown under glass and plastic for the past 30-40 years. Wells were drilled and the thermal energy was used for heating greenhouses which has made large scale vegetable production under glass and plastic profitable. Árpád uses 14 thermal wells (average depth 2 000 m, temperature 78-96ºC yield 60-70 m^3/hours) to heat 46 hectares of glasshouses and plastic tunnels as well as animal farms, a grain drier and social buildings. This is the world's largest agro-project use only geothermal energy.

PRODUCTION AND MARKETING

More than 500 families are growing vegetables – with the technical assistance of Árpád's engineers - under 23 ha glasshouses under 23 ha heated plastic tunnels, under 40 ha non heated plastic tunnels and on 50 ha open air. The total amount produced is around 10 000 tons a year and the turnover is 1,8 Billion Ft (more than 6 Million US$).

The most important product for Árpád is the white-yellow sweet paprika (cone shaped). The varieties are mainly Hungarian hybrids. This paprika is grown and sold each day of the year from

January till December. It is produced under glass, under heated plastic, and under non-heated plastic tunnels.

The next important crop is the tomato which is grown under glass (spring and autumn) and under heated plastic tunnels. The varieties are different Dutch varieties. On smaller acreages, Árpád produces in glasshouses hot green paprika (pepperoni) and cucumber.

The typical main crop under non-heated plastic is the yellow sweet paprika. As early spring crops Chinese cabbage and other Brassicas are in our product range, with a harvest in April, May. On open air (partly covered by flies plastic layer) we also produce Chinese cabbage and other Brassicas, Onion, Spice Paprika for milling. Árpád has well-trained effective plant protection and production technology. An Advisory Service Team helps Árpád to integrate the small individual growers. Altogether some 1 500-2 000 small producers are integrated in this way.

We also have coolhouses where products are stored. Árpád prepares the products for shipment for the home market or to abroad. One of Árpád's coolhouse complexes was modernised in 2000 which is now according the newest EC standard environment friendly. From our total turnover mentioned above about 30-40 % is going to export (+- 2 Million US$/year), and 60-70% for the home market.

The custom yard of Szentes is working at this modernised coolhouse where not only the products of ÁRPÁD, but products of other companies of the town are clearenced. The products of our company and products sold through the integration are well known in Germany, in Scandinavian countries, in Slowenia, Slovakia, in Chech Republic and in Austria.

CERTIFICATION PROGRAMMES

The Company Det Norske Veritas certified our vegetable production and sales according the ISO 9002 Standard in 1998. HACCP certification is also under preparation (for Chinese cabbage and paprika it has been completed). We also started the ISO 14000 Standard for horticulture production and sales.

As the custumers abroad and also on the home market are more and more interested in healthy products, Árpád started an Integrated Pest Management Programme several years ago. Bumblebees are used for better pollination and beneficials are used to control the different harmful insects. Árpád is also a distributor with exclusive rights for a Belgian company in this field.

In 2000 the operation was so successful that no chemical treatment was needed at all in some of our glasshouses involved in the project. In 2001 the start was not as easy as too many insects survived the mild winter, so we were facing much more problems than in 2000, and we had to spray against trips, and other insects.

METHYL BROMIDE USE AND PHASE OUT

As Árpád had fairly old production facilities (built in 1960's and 1970's) and the monoculture type of growing created more problems with soil born pests and diseases (especially nematodes and thrips), Árpád was one of the first companies in Hungary to obtain the right to use MB for disinfection of the soil of our greenhouses. Árpád and Zephyr Ltd are now the only importers of MB which was 27 tons in 2001.

As we became aware of the Montreal Protocol and the phase-out requirements, Árpád started to modernise its greenhouses for soilless rockwool technology. In 1998, a pilot glasshouse of 3 600 m^2 was prepared to grow tomato on rockwool. As the results were good we increased the field of tomato in 1999 to 1 ha. In 2000 paprika on rockwool was grown on 2 ha. Based on a successful project with the Ministry of the Netherlands Árpád made a big step in 2001 as another 4 ha of paprika on rockwool was started. In 2002 a further 4 ha investment was completed for 2 ha paprika, 1 ha tomato and 1 ha cucumber. For the time being, 11 ha rockwool is in production and we have our further efforts to increase this. Of course, the investment costs and support for modernising such an old operations have also been determined to meet the phase out of MB.

PROGRAMME WITH GRAFTED PLANTS

Árpád considers grafted plants as a good solution for use in heated plastic tunnels. The heated plastic tunnel units in practice are too small, they have small air spaces, are having different heating possibilities and also problems with irrigation water quality (filtering needed). These condistions make growing plants on rockwool almost impossible. Grafted paprika plants solve some of these problems.

These grafted plants we buy from Italy. The root plant is Snooker the producing plants are the traditional varieties. The much stronger and bigger root mass is supplying the upper producing plants with more water and feed and minerals, and the stronger crop is more resistant to stress and to any diseases, viruses, bacterias etc.

Also the larger root is more tolerant to nematodes and consequently much larger leaf mass is developed and larger yields could be expected. To save costs, the bigger roots allow us to use two main stems if compared with the traditional growing technic where only the main stem is used.

The first trials we made in 2000 with grafted paprika culture under heated plastic were quite promising. Based on trial results today some of our colleagues decided to use under their private heated plastic tunnels grafted plants.

SOLUTIONS FOR NON-HEATED PLASTIC TUNNELS

As we have the possibility to move to new land (move the tunnel to a new area), this could solve the problems related with soil born pests and diseases.

Other possibilities with alternative chemicals and growing technics we could rely on “The Regional Demonstration Project conducted in Poland”. Also the grafted paprika growing technique combined with some chemical treatments could bring good results under non-heated plastic tunnels.

COMMUNICATION OF RESULTS OF PROGRAMMES

Árpád organised two workshop days (one in Spring one in Autumn) and invited growers from all over Hungary and specialists from abroad to make presentations. Last time we organised on 6th and 7th of April 2001 two very successful Workshop days (we call it “Day of the Open Gates”) as we let the visitors to see everything. This time the subjects were: “Soilless paprika growing under greenhouses and the new technology with the grafted plants”. *Árpád* also has its own newsletter which is sent to all growers involved in production. *Árpád*’s specialists also write articles for the growers interest’s and publish in periodicals such as “Horticulture and Vinary”, “Plant protection”, “Hungarian Agriculture”. In addition to local growers, *Árpád* also receives groups that are participants from abroad taking part on congresses, seminars and workshops.

Table 1 and Figure 1 summarise the results of the new techniques. Of course, the operating costs are higher on rockwool and with grafted plants, but still bring a profit and a healthier product. *Árpád* calculates investments costs to be returned in a max. of 4-5 years. Investment costs include: Soil removal 5 000 m^3/ha, in order to increase the possible height of the crop; change of old isolation, broken glass; new heating system; new drip irrigation system; new irrigation water cleaning system; new irrigation water distribution system.

Table 1: Summary of economic impact comparison of yields, incomes of different cultures and growing methods (Glasshouse season 2000-2001)

Data	Tomato		Pepper		
	In soil	rockwool	In soil	grafted	rockwool
Yield kg/m^2	22[1]	40	12-13[2]	16,5	22-23
Income Ft/m^2	3 800	6 000	2 800	3 700	6 000
Mbr cost Ft/m^2	190	-	190	190	-
Investment costs Ft/m^2	-	5 000	-	-	5 000

[1]Tomato in soil 2 crops spring and autumn. [2]One spring crop only

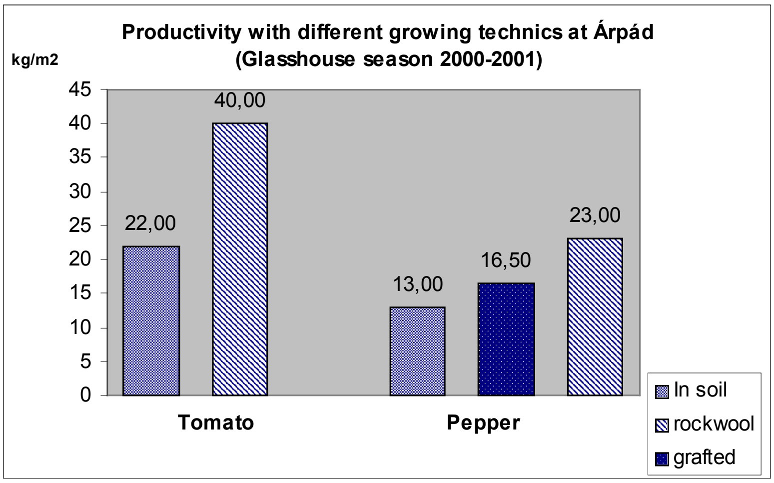

Figure 1: Productivity of tomato and pepper grown in soil, rockwool and grafted

Árpád sees in 2005 as the deadline for equipping all of its greenhouses with the rockwool growing technique thereby avoiding the need for MB or other chemical for soil disinfestation. By managing this great step *Árpád* hopes to create a healthier environment.

NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USE IN JORDAN

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ABSTRACT

Jordan consumes about 350 tonnes per year of methyl bromide (MB). This amount is used to fumigate the soils of plastic houses which are planted mainly with cucumber and tomato. The number of plastic houses in Jordan ranges from 30,000 to 35,000 in the irrigated areas.

Jordan has signed Montreal Protocol to phase out MB. Jordan, however, is trying to phase out MB by the year 2005. A research project was established to find out the suitable alternative(s) that could replace MB in protected agriculture in Jordan.

Two sites were chosen in different agro-climate zones. Alternatives such as soil steaming, biofumigation, soilless culture, and chemicals were tested. MB and control treatments were added. Six treatments were conducted in each plastic house with four replications.

Results showed that soil steaming and biofumigation alternatives had a positive effect on reducing soil pathogens, but control was less effective than MB. Total crop yield of cucumber under the three alternatives (steaming, biofumigation and basamid) was slightly lower than MB, and higher than control treatment in both sites. Soilless culture, however, may produce higher yield but the system requires more experience before it can be applied commercially.

Keywords: methyl bromide, soil steaming, soil biofumigation, root-knot nematode, *Fusarium*.

INTRODUCTION

Methyl bromide (MB) is a broad-spectrum chemical commonly used as a soil fumigant to control of soil borne diseases, nematodes, insect pests and weeds. Between 30 and 85% of the total MB applied to the soil reachs eventually the atmosphere. It is now recognized that MB contributes significantly to ozone depletion and was listed as an ozone-depleting substance (ODS) by the Parties to the Montreal Protocol in 1992 (UNEP 2001). The development of a comparable agricultural system without the use of MB, in many cases, will require extensive research to achieve a similar spectrum of efficacy and reliability.

The horticulture sub-sector in Jordan is being subjected to high intensification using the latest technology. Jordan is considered as a big producer and exporter of vegetable crops to the neighboring states.

Actually the total consumption of MB in Jordan for soil fumigation is estimated to be c. 350 tonnes per year. It is used to sterilize seedbeds in nurseries and for plastic house vegetable production (tomato, cucumber, sweet pepper, strawberry). Up to 97% of MB used in Jordan is applied in the Jordan Valley. The majority of the farmers (82%) apply MB once a year. The total treated area can be estimated by 43% of the total area of plastic houses in Jordan.

Root knot nematodes are important phytopathogenic nematodes causing large economic loses. The species *Meloidogyne incognita* and *M. javanica* are present with a differential distribution of species. *M. javanica* is mainly present in the areas with higher temperatures found in the southern Jordan Valley, whereas both species are present under more temperate climatic conditions of the middle and northern Jordan Valley. Fungal diseases, however, include *Fusarium oxysporum*, *F. solani*, *Pythium* spp. *Sclerotinia* spp. and *Verticillium* spp. A synergistic effect between root knot nematodes and *Verticillium* wilt has been observed.

Non-chemical alternatives such as solarization, biofumigation, soil steaming and soilless culture are recognized as effective alternatives. The main objective of this study is to determine the suitable alternative(s) that could replace MB use in the protected agriculture in Jordan.

MATERIALS AND METHODS

Cucumber crop was chosen to test different alternatives to the use of MB. Cucumber accounts for 48% of MB usage in Jordan. The sites were selected according to their differential agro-ecologic characteristics, as well as actual and potential use of MB.

The experimental sites were located in Deiralla area (Middle Jordan Valley) and irrigated Up-lands. The chosen areas accounted for 53% of the total MB use. Both sites were approved after conducting several laboratory tests for many farms in order to find contaminated farms with soil borne diseases (nematodes and fungi). Both sites were intensively cultivated in the past five years. Drip irrigation and black plastic mulch to control weeds are common practices at both sites.

The middle Jordan Valley site elevation is 224 m below sea level. Soil type was classified as silty clay (clay 46%, sand 13%, silt 41%). Soil pH ranged from 7.9 to 8.2 and soil EC ranged between 3.7 and 5.2 dS/m. Water pH was 7.8 and EC was 2.0 dS/m. Date of planting was on 20 December 2000.

The Upland site elevation is 720m above the sea level. The soil type was classified as clay soil (74.9%). Soil pH ranged between 7.2 and 8.3 and soil EC ranged between 1.8 and 4.9dS/m. The field was irrigated from the under ground water where water pH was 7.4 and EC was 0.9 dS/m. Date of planting for the Upland site was 22 April 2001.

Four different alternatives (Biofumigation, Soil Steaming, Soilless culture and Basamid) were chosen for each site. These alternatives were compared with MB treated and untreated plots (control).

Biofumigation treatment was applied by adding fresh manure (7 kg/m^2) to the soil surface and well mixed then the plots were watered. The plots were covered by plastic sheets (200 u thick) for 15-30 days. After the plastic sheets were removed, the soil was ploughed, levelled and biocont (*Trichoderma*) added in an average of 7 g/m2 and (*Peacillomyces*) was added in an average of 2 g/m2 immediately before planting (Jatala 1986, Kabana and Morgan 1987). Data logger was used to determine soil temperature at different depths.

Soil steaming treatment was applied when the plots were leveled. The plots were covered by heat tolerant plastic sheet and soil surface was steamed until the soil temperature reached 70 - 90°C at 20 cm depth. The soil was aerated and biocont (*Trichoderma*) was added in an average of 7 g/m^2 and 2 g/m^2 *Peacillomyces* immediately before planting.

Soilless culture treatment was applied to six rows 9 m long and 0.4 m wide together with plastic sheets 1000 microns thick added to each plot. Rows were filled with tuff media in three layers (5cm of 10-20 mm particle size, 10 cm of 4-8 mm, and 5 cm of 0-4 mm particle size). Nutrient solutions were added by fertigation system.

The plots of chemical treatment (Basamid G) were cultivated and flooded by water in order to encourage weed growth. The soil then was ploughed, leveled and Basamid was uniformly broadcasted at an average of 50 g/m^2 and mixed well with 10-15 cm of the soil surface when soil moisture was about 40% of the field capacity. The plots were then irrigated and covered with plastic sheet (200 microns thick). The plastic sheets were removed after three weeks of application to allow soil ventilation for four days before planting.

Five soil samples from each plot were taken randomly. The soil samples were taken from the top 30 cm. The samples were thoroughly mixed and a composite sample was prepared. The type and number of fungal propagules were determined by soil dilution methods. The type and number of plant parasitic nematodes were determined according to the modified Baemann funnel method.

Four plastic houses (9 X 56 m) with complete fertigation systems were installed at each site. Each plastic house contained one replicate. The experimental design was completely randomized blocks with six treatments in each plastic house.

RESULTS AND DISCUSSION

Control percentage of both *Fusarium* and free-living nematodes was higher using MB and soil steaming treatments immediately after application in both sites. On the other hand, biofumigation treatment after application showed better control for free-living nematodes than *Fusarium*, especially in the Upland site (Tables 1 & 2).

However, developing *Fusarium* and second stage nematodes with periods of cucumber growth showed higher control with MB for both diseases in both sites (Table 3 & 4). Soil steaming showed better negative effect on *Fusarium* with time than on second stage nematodes in both sites. Whereas, biofumigation showed better effect on second stage nematodes than on *Fusarium* in both sites. The action of microorganisms on the manure during its decomposition produce substances such as ammonia, nitrate, hydrogen sulfide and a great number of volatile compounds and organic acids that are effective in controlling soil pathogens. Average soil temperature at 20 cm depth in the period of biofumigation treatment ranged from 5.9 to 8.6^{o}C higher than the soil temperature of the control treatment at the same depth in both sites. This may provide a reason for the increase in soil temperature was not high enough to control *Fusarium* (Brid 1972).

Average plant fresh weight was lower under chemical and control treatments in both sites (Table 5). However, total cucumber yields under the three alternatives (biofumigation, soil steaming and basamid) were slightly lower than MB and higher than control treatment in both sites (Table 5). Soilless culture treatment may produce higher yield but it requires more experience to apply and monitor the system.

This preliminary study suggests that soil steaming, biofumigation and soilless culture are potential non-chemical alternatives to MB fumigation for soil pathogen control. Developed soilless culture technique may need further experience to be accumuled by farmers before it can be adopted.

TABLE 1: Average number of *Fusarium* (propagules/gm oven dry soil) before and after treatment application in Jordan Valley and Upland sites.

Treatment	Jordan Valley			Upland		
	Before	After	Control %	Before	After	Control %
MB	89.5	0.0	100.0	103.3	33.0	68.0
Biofumigation	102.0	52.3	49.0	110.0	70.8	35.6
Basamid	63.8	54.8	14.0	98.8	47.0	52.4
Soil Steaming	75.5	4.3	94.0	128.3	20.0	84.4

Soil steaming technology, however, may be applied via contract services. In conclusion, these results show that there are non-chemical alternatives to MB fumigation for Jordan vegetables. Farmers will ultimately determine which of these alternatives are feasible for their individual operations.

TABLE 2: Average number of soil borne free-living nematodes (*Rhabditis*/100cm^3 soil) before and after treatment application in Jordan Valley and Up-land sites.

Treatment	Jordan Valley			Upland		
	Before	After	Control %	Before	After	Control %
MB	241.5	0.0	100.0	1325.0	154.0	88.4
Biofumigation	192.5	92.8	51.7	1259.3	339.5	73.0
Basamid	187.3	22.8	87.8	1087.5	175.0	83.9
Soil Steaming	126.0	19.3	84.7	1022.5	56.0	94.5

TABLE 3: Average number of *Fusarium* (propagules/gm oven dry soil) with periods of plant growth (days) in Jordan Valley and Upland sites.

Treatment	Jordan Valley			Upland			
	25 d	90 d	140 d	25 d	65 d	103 d	135 d
MB	0.0 b	28.5 c	56.5 c	33.0 bc	14.0 b	70.8 c	62.5 c
Biofumigation	52.3 a	150.0 a	93.5 a	70.8 a	15.0 b	118.0 ab	92.0 b
Basamid	54.8 a	51.5 b	61.5 b	47.0 b	40.0 a	135.8 a	131.0 a
Soil Steaming	4.3 b	40.3 bc	64.0 b	20.0 c	0.0 c	95.5 bc	78.0 c

TABLE 4: Average number of second stage nematodes (*Meloidogyne*/100 cm^3 soil) with periods of plant growth (days) in Jordan Valley and Upland sites.

Treatment	Jordan Valley			Upland			
	25 d	90 d	140 d	25 d	65 d	103 d	135 d
MB	0.0	0.0	0.0 d	0.0	0.0	0.8 c	2.5 c
Biofumigation	0.0	0.0	0.6 c	0.0	0.0	21.0 b	31.5 bc
Basamid	0.0	0.0	57.8 a	0.0	0.0	29.8 a	77.0 a
Soil Steaming	0.0	0.0	17.7 b	0.0	0.0	33.3 a	44.8 b

TABLE 5: Total cucumber yield (kg/plant) and plant fresh weight (g/plant) at experiment termination in Jordan Valley and Upland sites.

Treatment	Jordan Valley		Upland	
	Fruit Yield (kg)	Plant Fwt (g)	Fruit Yield (kg)	Plant Fwt (g)
MB	4.38 ab	703.1 a	4.13 a	1150.0 a
Biofumigation	3.69 bc	537.5 b	4.11 a	975.0 b
Basamid	3.69 bc	503.3 c	3.78 bc	931.3 bc
Soil Steaming	3.96 b	581.3 b	4.15 a	1162.5 a
Soilless Culture	5.32 a	-------	3.82 b	-------
Control	3.44 c	503.1 c	3.60 c	831.3 c

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NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USED IN GREECE ON HORTICULTURAL CROPS

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ABSTRACT

Extensive research on solarization in Greece was shown to be effective in reducing diseases of vegetables and increasing yield. tomato soilborne pathogens for two consecutive cropping seasons. Soil solarization for 3 weeks with impermeable plastics was efficient in almost nullifying the percentage of diseased tomato plants during the first cropping season and avoiding *Meloidogyne* infection. Solarization significantly inhibited root infection by *Meloidogyne* in the second cropping season indicating a long-term effect of solarisation. Reduced duration solarization using impermeable plastics could be a valuable alternative to methyl bromide fumigation in Greece. Research should continue to assess a combination of antagonistic organisms with soil solarization. It is possible that duration of solarization could be further reduced if properly combined with tolerant or resistant rootstocks against several diseases of vegetables.

INTRODUCTION

Vegetable cultivation in Greece has been based on methyl bromide (MB) fumigation for several years. In parallel, the Greek climate favours application of soil solarization as a MB alternative for controlling soilborne pathogens of vegetables. Experiments on soil solarization for the last 25 years in Greece were effective in restricting diseases and increasing yield with a drastic reduction in the density of fungal propagules in vegetables. Although classical soil solarization is effective, its extensive commercialization as a non-chemical alternative has been rather restricted in certain regions of Greece.

The main soilborne pathogens of tomato cultivation in Greece are *Pyrenochaeta lycopersici, Fusarium oxysporum* f.sp. *radicis lycopersici, Verticillium dahliae, Phytophthora* sp. and *Clavibacter michiganensis* subsp. *michiganensis.* Furthermore *Meloidogyne* sp. is becoming a limiting factor particularly for summer plantations. Similarly soilborne pathogens including *Verticillium dahliae* and *Fusarium oxysporum* are also limiting factors for out of season cucumber, melon and watermelon cultivation. Artichokes, eggplants strawberries and peppers are also suffering from serious soilborne pathogens such as *Verticillium dahliae.*

RESULTS

Short-term soil solarization using impermeable plastics (polyamide plastic sheets covered with polyethylene) seems to be a good approach in convincing the farmers to apply solarization. This was first demonstrated by using short-term soil solarization and biocontrol agents against *Fusarium oxysporum* f. sp. *cucumerinum, Fusarium oxysporum* f. sp. *radicis-cucumerinum* of cucumbers, and *Fusarium oxysporum* f. sp. *niveum* of watermelons.

Experimental trials were recently carried out to control the main tomato soilborne pathogens for two consecutive cropping seasons. Soil solarization with impermeable plastics was efficient in almost nullifying the percentage of diseased plants during the first cropping season (winter-spring). No difference among 3 and 4 weeks solarization was observed, proving that 3 weeks solarization was more than enough when impermeable plastics were used. No *Meloidogyne* infection was observed. During the second cropping season during summer-autumn, all treatments significantly inhibited root infection by *Meloidogyne* indicating a long-term effect of the method.

CONCLUSIONS

It seems that reduced duration of solarization using impermeable plastics could be a valuable alternative to MB fumigation in Greece. Research should continue to assess a combination of antagonistic organisms with soil solarization. It is possible that duration of solarization could be further reduced if properly combined with tolerant or resistant rootstocks against several diseases of vegetables. Melons, watermelons and cucumbers are suffering from Fusarium wilts and resistant rootstocks are available against these pathogens. However, resistance against other soilborne pathogens such as *Verticillium dahliae i*s not available. Therefore, combination with solarization is a recommended alternative.

More recently work on biofumigation in controlling Fusarium wilt of Asparagus was also initiated in asparagus plantations in northern Greece.

Solarization could also applied in nurseries prior to young tree establishment to avoid infection by soilborne pathogens. Individual soil solarization was applied in the past against Verticillium wilt in existing olive, pistachio nut and almond orchards.

NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USED IN MACEDONIA ON VEGETABLES

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ABSTRACT

The Republic of Macedonia produces a wide range of vegetables, the most important being tomatoes, peppers, cucumbers, cabbage, watermelons and melons. Greenhouse vegetable production is important for the export of fresh vegetables such as tomatoes and cucumbers. The reported use of MB in Macedonia in 1999 was 21.0 tonnes of which around 10% was used in vegetable production. In trials using MB, biofumigation + solarisation and dazomet, all treatments reduced rootknot nematodes and the indicator pathogen *Fusarium* to acceptable levels. Solarisation + biofumigation gave the best tomato yields of 126 tonnes. In the trials where cucumber was grown as the second vegetable crop, solarisation + biofumigation again gave the highest yield of 235 tons/hectare. MB treatment was the most costly at $65,280/ hectare for tomato and $42,248 for cucumbers, compared to $59,514 and $41,516 respectively for solarisation + biofumigation. The market price of the tomatoes was the same for all treatments but increased profitability using the alternative was largely due to higher yield and lower production cost.

Keywords: tomato, cucumber, methyl bromide, alternatives, solarisation, biofumigation, dazomet, rootknot nematode, *Fusarium*

INTRODUCTION

Production of vegetables has a special significance in the agriculture of the Republic of Macedonia. The suitable climate offered by the area enables the production of a wide range of vegetables, the most important being tomatoes, peppers, cucumbers, cabbage, watermelons and melons. Vegetables are produced on a total area of 56,000 hectares. Approximately 200-250 ha of production is in heated glasshouses. Greenhouse vegetable production is important for the export of fresh vegetables such as tomatoes and cucumbers, although greenhouses comprise only 0.2 % of the total arable land. Greenhouse cropping is considered to be a profitable activity provided it is reshaped to cope with market changes and other transformations of the region. The export – import of vegetables is highly successful, mainly due to greenhouse production.

The total production from greenhouses is about 19,000 tonnes. Two production cycles are practised per year so that crops are ready for harvest when market prices are highest. The first cycle starts in mid-January (or in February to avoid high fuel costs) and ends in mid to end June, or later. The second cycle starts at the end of July and finishes in November or December. The typical yield of tomato ranges from 100 to 130 tons per hectare, while cucumber yields are in the range of 160-200 t/ha.

The use of methyl bromide (MB) is limited to tobacco seedbeds. The reported use of MB in 1999 was 21.0 tonnes. A survey carried out by the Faculty of Agriculture during 2000 indicated that the real use of MB was probably twice that figure. Around 10% are used in vegetable production. From 1994 the use of MB in horticulture was banned. For that reason horticulture does not use large 50 litre cylinders of MB, but the small 454 ml cans permitted for tobacco seedbeds.

MB can be used for common soil-borne problems such as the following: weed control; damping off (*Phytophthora, Pythium* and *Rhizoctonia*); fusarium wilt (*Fusarium oxysporum*); verticillium wilt (*Verticillium dahliae*); bacterial canker (*Corynebacterium* spp.); alternaria stem canker (*Alternaria alternata*); late blight (*Phytophthora infestans*); root knot nematodes (*Meloidogyne* spp.)

METHODS

Biofumigation combined with solarisation consists of mixing moist soil with organic matter and heating it by covering with a transparent plastic sheet. The soil temperature increases to a level that is lethal to many soil-borne pests and diseases. At the same time, the raised temperature favours the fermentation of the organic matter, generating gases that are trapped beneath the plastic and lethal to many undesirable microorganisms in the soil. The addition of organic matter reduces the time required for solarisation.

Cow manure at a concentration of 5-7 kg/m^2 is well distributed and incorporated into the soil to 20 cm depth. The soil is than irrigated with 30 mm of water, which should enable intensive decomposition of the manure and covered with transparent polyethylene. The process of decomposition is considered to be finished when the temperature starts decreasing down to 25^0C. In the Macedonian climatic conditions (summer time) it takes two weeks to complete this procedure. However, it was found that when temperatures are not sufficiently high cow manure can introduce weed seeds, so it preferable to consider other organic sources of isothiocyanates, such as plant residues from the cabbage family.

RESULTS AND DISCUSSION

A demonstration project on alternative to MB was carried out in Macedonia to compare MB, biofumigation + solarisation and Dazomet. All treatments reduced root knot nematodes and the indicator pathogen *Fusarium* to acceptable levels. The heat of solarisation controlled most pathogens in the upper 20 cm of soil. In the comparative trials, solarisation + biofumigation gave tomato yields of 126 tonnes, which was by far the highest of the three treatments. The control gave the lowest yield of 101 tons per hectare. In the trials where cucumber was grown as the second vegetable crop, solarisation + biofumigation again gave the highest yield of 235 tons/hectare. The results are shown in Table 1.

Table 1: Yield of greenhouse tomato and cucumber

Treatment	Average yield (tonnes/hectare)	
	Tomato	Cucumber
Control	101.4	158.8
Methyl bromide	114.0	202.0
Solarisation + biofumigation	126.0	235.6
Low doses of chemicals	113.0	222.2

In the case of tomatoes, production with MB was the most expensive method. The total production costs using MB were $65,280/ hectare for tomato and $42,248 for cucumbers, compared to $59,514 and 41,516 respectively for solarisation + biofumigation. Likewise, MB was less profitable, giving gross profits of only $48,720 her hectare compared to $66,486 per hectare from solarisation + biofumigation in the case of tomato (Table 2). The market price of the tomatoes was the same for all treatments (about $1 per kg). The increased profitability of the alternative was largely due to its higher yield, and partly due to its lower production cost.

Table 2: Cost of production and gross profit in greenhouse tomato and cucumber [US$/ha]

Treatment	Total production cost	Gross income	Gross profit
Tomato			
Control	58,350	101,400	43,050
Methyl bromide	65,280	114,000	48,720
Solarisation + biofumigation	59,514	126,000	66,486
Low dose chemicals	62,148	113,000	50,852
Cucumber			
Control	39,023	95,280	56,257
Methyl bromide	42,248	121,200	78,952
Solarisation + biofumigation	41,516	141,360	99,844
Low dose chemicals	42,972	133,320	90,348

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MEASURES AND ACTIVITIES THAT ASSIST WITH THE PHASE OUT OF METHYL BROMIDE

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ABSTRACT

By the end of 2001, about 135 countries had ratified at the national level the methyl bromide (MB) phase-out commitments of the Montreal Protocol. Countries typically regulate the consumption (national supply) of MB by limiting the quantity of MB that can be imported. During the phase-out of other ozone depleting substances (ODS) such regulations were often augmented by non-regulatory activities to assist ODS users in converting their operations to ODS-free methods. This paper identifies activities that may assist MB users in their phase-out efforts, drawing on experiences in several ODS sectors. Montreal Protocol projects in developing countries have shown that trials and demonstrations of MB alternatives can play a very useful role; other useful activities include the provision of information resources, use of economic signals, encouragement for companies to review their policies and contracts, and the development of new industries to provide alternative products and services in rural areas.

INFORMATION RESOURCES

Information about local alternatives

MBTOC, the Montreal Protocol's technical committee on MB, provides reports on existing and potential alternatives; of necessity this information is global in scope. MB users would benefit from additional local publications that focus on local MB uses and pests, and related alternative pest control methods. In Scandinavia, for example, the Nordic Council assisted MB users in the mid-1990s by publishing information on MB alternatives relevant to the region (Nordic Council 1993, 1995, 1997; Danish EPA 1997). In Australia, researchers met with local groups of growers to identify the most promising MB alternatives for local situations; they publish updates for growers, describing results of regional trials and demonstrations (Porter 2002).

Technical 'how to' booklets for farmers

Traditionally, extension organisations have provided practical booklets for farmers, detailing how to apply certain agricultural techniques. The Agriculture Ministry in Belgium, for example, published a series of booklets on production methods for strawberry, tomato, cucurbits, lettuce and ornamentals. Likewise, the University of California extension service publishes integrated crop production manuals in hard copy and on the internet for strawberry, tomato, cucurbits, cut flowers and other horticultural crops, as well as booklets on techniques such as solarisation.

In the post-harvest area, GTZ has published practical booklets on methods of stored product protection (GTZ 1996). Several 'how to' booklets have now been produced specifically on MB alternatives, and more are in the pipeline. For example, a leading tobacco company in Brazil has published farmer leaflets that describe how to build and use the floating tray system for tobacco seedlings. UNEP has recently published a manual on the production of cut flowers without MB (Pizano 2001). Many of the MB projects carried out by developing countries (under the Montreal Protocol) plan to publish practical booklets for growers, describing how to apply MB alternatives.

To assist MB phase-out in Europe, technical booklets could be produced at local level, giving details in a practical and user-friendly style, including diagrams, pictures and comments from growers who have experience with alternatives.

Lists of companies who supply alternatives

Farmers and other MB users need to know where they can find suppliers of alternative equipment, products and services; lists of companies and suppliers can provide a useful resource (Miller 1997). UNEP has published a series of Sourcebooks on suppliers of ODS alternatives for CFCs and halons, and recently published a similar Sourcebook for MB (Miller 2001). It lists examples of companies who manufacture and/or supply alternative products and services, and provides contact details of specialists.

Companies who supply chemical or non-chemical alternatives have an important role to play in MB phase-out. For EU users it would be useful to compile regional lists of suppliers of all types of relevant products, such as alternative fumigants, application equipment, cheap substrate materials, sheets for solarisation and biofumigation, organic matter for biofumigation, etc. Lists should include companies/organisations who provide related services such as pest identification, training in IPM and MB alternatives, alternative fumigation services, portable steam treatments, and technical advice on the control of soil-borne pests.

Brochures about new business opportunities

The Canadian government has noted that ODS phase-out provides an opportunity to develop new businesses and new industries, at the same time as benefiting the environment (Environment Canada 1996). Rural economic development programmes could consider identifying and distributing information about the business opportunities arising from MB phase-out, particularly opportunities for small and medium sized enterprises (SMEs) in rural areas. Since most countries import MB, there are opportunities for import substitution. There are also opportunities to develop new export sectors to meet the worldwide demand for MB alternatives.

Label information for MB users

Information on labels can help to inform and warn ODS users about the problem of ozone depletion, raising their awareness. Under the US Clean Air Act, for example, containers of MB and other ODS in inter-state trade are required to carry a special label which reads: 'Warning: contains [name of ODS], a substance which harms public health and environment by destroying ozone in the upper atmosphere' (Clean Air Act section 611).

ECONOMIC SIGNALS TO PROMOTE ALTERNATIVES

Levies and taxes to fund alternatives

Some countries have placed levies or taxes on ODS and pesticides in order to raise funds for the promotion of alternatives. From 1995 Australian MB users and importers introduced a levy on sales of MB to generate funds for trialing alternatives. At present the levy is about € 0.18 per kg and raises approximately € 134,000 per year, which is matched by funds from the government, giving about € 268,000 per year for the adaptation and improvement of alternative techniques and communications with growers (Porter 2002). The Czech Republic's ozone protection legislation placed duties of about € 6 per kg on imports of MB and other ODS, and the revenue is used by a state Environmental Fund for ozone layer protection (Parliament of the Czech Republic 1995). Also based on the 'polluter pays' principle, Denmark and Sweden have placed environmental taxes on sales of pesticides in general, raising funds for research on non-chemical and IPM techniques (MBTOC 1998).

Tax rebates for alternatives

Some governments have reduced import duties and company taxes on non-ODS equipment and products, to make investment in alternatives more attractive to ODS users. Malaysia and Singapore, for example, granted reductions in company tax for firms who invest in ozone-friendly technologies. India waived customs duties on imports of non-ODS manufacturing equipment (Miller 1999a).

Grants and subsidies

A number of governments promote agricultural innovation and exports by providing grants or subsidies for specific activities. These can give important economic signals to farmers and can help determine their choice of pest control methods, including MB or alternatives. The regional government of Ragusa in Sicily, for example, introduced a programme to promote new agricultural technologies - they subsidised the purchase of plastic sheets for solarisation (25% of cost reimbursed), and machinery (13% reimbursed) to lay plastic for open-field solarisation; irrigation systems were also subsidised (Vickers 1995).

The EU Common Agricultural Policy (CAP) has several funding mechanisms that could be used to assist MB users in the adoption of alternatives, such as: grants for investing in farming methods that reduce the polluting effects of agriculture, grants for training in agricultural practices for environmental protection and modern requirements. Several rural development programmes provide funds for advisory services, technical assistance and training, demonstration projects and pilot projects (Prospect 1997; Smeets 1998). It would help MB users in Europe if extension bodies or other groups would publish local/national guides to the agricultural programmes which offer assistance relevant to the adoption of MB alternatives.

COMPANY POLICIES

Companies who purchase large volumes of fruit, vegetables and stored products often set conditions or specifications for product quality and other parameters in their contracts with suppliers. Increasingly, environmental aspects are being considered. Food manufacturers, traders and supermarkets can play a positive role in identifying MB alternatives, reviewing their company policies and contracts, eliminating requirements for suppliers to use MB, and actively encouraging the adoption of alternatives (Miller 1999b).

Company policies

Some food manufacturers and supermarkets actively promote integrated pest management programmes, which can have an impact on MB use. For example, Sainsburys in the UK reported that its IPM programme did not permit the use of MB for certain crops, while in other crops MB use was being reduced (Prospect 1997). Some of Sainsburys' contracts specifically prevent the use of MB by suppliers. The Co-op supermarket organisation owns a number of farms in the UK, and banned the use of MB as a soil fumigant on these farms in the mid-1990s (Co-op 1996). The Co-op announced last year a new code of practice developed with its suppliers which will prohibit 24 pesticides including MB, as a result of rising consumer concerns about health and environmental impacts (Buffin 2001a). Marks & Spencer has announced a plan requiring its suppliers around the world to reduce and phase out the use of 79 pesticides that pose risks to health or the environment; MB is included in this list (Buffin 2001b).

In Spain, the Association of Harvesters and Exporters of Fruit and Vegetables in Almería (COEXPHAL) has had 25 years of experience in intensive horticulture in the south-eastern part of Spain. From 1997, growers have been requested not to use methyl bromide (MB) as a policy of the Association and today MB is no longer necessary for production (Fernandez 2002).

Environmental grading and certification systems

Industry environmental standards and certification programmes can assist the adoption of MB alternatives. For example, auction houses in the Netherlands have established an environmental certification and grade system for cut flowers, called MPS, in which farmers reduce their use of pesticides, fertilizer, water and energy. MB cannot normally be used in the production of MPS grade flowers. Around 5,000 farms implement the MPS programme in 22 countries, including the Netherlands, Belgium, Italy, France, USA, Israel, Kenya, Zimbabwe, Zambia, Costa Rica and Ecuador (de Groot 2001). "Eurepgap" standards in the European Community are promoting production of crops without the use of MB (Moeller 2002).

Consumer information

TEAP, an advisory body to the Montreal Protocol, has noted the role of environmental labelling in consumer decision-making on ODS and concluded that 'Parties [countries] that are not yet using eco-labelling systems to promote the objectives of the Montreal Protocol might consider the benefits of adding such a market-based measure to their ozone protection policies.' (TEAP 1997).

In the case of MB, some consumer and environmental organisations (eg. Natural Resources Defense Council in USA, Friends of the Earth, Pesticide Action Network) have pressed for the labelling of products grown with or without MB so that consumers will be able to exercise a choice when they purchase fruit and vegetables (MBTOC 1998). In several cases producers have placed labels on packages to inform consumers that MB has not been used. For example, GTZ agricultural projects in Jordan have developed a certified label for IPM products and those grown without use of MB. When the MB labels were trialed on packs of fresh strawberries exported to supermarkets in Europe, the retailer gave positive feedback and encouraged the producer to continue labelling products in this way (Hasse 2001).

Company leadership in the commercialisation of alternatives

TEAP has highlighted the important role of companies who decide to take a leadership role in the development and commercialisation of non-ODS products and services (TEAP 1997). In the 1990s in the USA, a pest control company called Fumigation Service and Supply took a leading role in trials and commercialisation of MB alternatives for commodities and structures such as food processing plants and flour mills (MBTOC 1998, Mueller 1998). In Peterborough Canada, the Quaker Oats food processing facility developed innovative and effective pest control systems based on sanitation, IPM and heat treatments; while the Canadian Pest Control Association has strongly promoted IPM MB alternatives since the mid-1990s (Health Canada 1998, Environment Canada 1995).

Certain governments actively encourage companies to take a leadership role in ODS phase-out. For example, the US EPA holds an annual award ceremony for companies who show leadership in ozone layer protection (US EPA 1997).

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ECONOMIC IMPACT OF METHYL BROMIDE PHASE-OUT IN THE UNITED STATES OF AMERICA

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ABSTRACT

As research has progressed on alternatives to methyl bromide (MB), the estimate of the economic impact of the U.S. ban on its use have been revised from $1.5 billion annually to $500 million annually. Using a value of marginal product approach as done here results in a loss estimate of $624 million per year. Sixty-nine percent of the annual economic impact will be incurred when the final 30% reduction is required in 2005. Permitting quarantine uses and critical use exemptions under the harmonization of the U.S. Clean Air Act with the Montreal Protocol phase-out schedule may lessen the economic burden until new pest control strategies are adapted for use.

INTRODUCTION

The U.S. Clean Air Act requires the phase-out of any substance with an ozone depletion level (ODP) of 0.2 or higher. When the Montreal Protocol parties listed methyl bromide (MB) with an ODP of 0.7 (revised to 0.6) in 1992, the U.S. Environmental Protection Agency (EPA) instituted a ban on the production and importation of MB after 1 January 2001, permitting no exemptions for quarantine uses. When the Protocol parties adopted a phase-out schedule in 1997, the U.S. Congress amended the Clean Air Act to harmonize the U.S. and international schedules. Under this harmonization, the EPA has mandated a 25% reduction from 1991 levels in production, importation and consumption by 1999; a 50% reduction by 2001, a 70% reduction by 2003 and a 100% reduction by 2005. However, pre-shipment and quarantine uses of MB and critical and emergency use exemptions will be permitted after 2005. The U.S. EPA published an interim exemption proposal for quarantine and pre-shipment uses in July 2001. In 2001, the Montreal Protocol agreed to a time line as well as data requirement to determine critical use exemptions. The U.S. plans to solicit critical and emergency use exemption applications in early 2002.

Although it has reduced its use from a baseline of 25,528 tonnes in 1991 to 17,425 tonnes in 1999 (a reduction of 31.7%), the U.S. continues to account for 92 percent of the North American MB use (EPA, 2001a). These 17,000 tonnes of MB are used as a pre-plant fumigant, concentrated in tomatoes, strawberries, peppers, nursery crops, seed beds, grapes, and watermelon (Table 1). MB is also used to fumigate orchards and vineyards before replanting. Use is expected to decrease to less than 13,000 tonnes (49.1%) in 2001. Production is expected to decrease more than 10,000 tonnes in 2001 (EPA, 2001a). Part of this use reduction is due to the fact that the average price of MB in the U.S. has increased by almost 270 percent from $1.23 lb in 1995 to $4.50 lb in 2001 (UNEP/TEAP 2001).

Table 1: United States MB pre-plant use by crop (tonnes)

Crop	1997	Percent of Total Use	Estimated 2000 Use
Tomato	4409	25.6	3944
Strawberry	3889	22.6	2282
Peppers	1843	10.7	1261

Crop	1997	Percent of Total Use	Estimated 2000 Use
Grapes	1382	8.0	376
Nursery	1363	7.9	626
Seed beds	975	5.7	569
Watermelon	639	3.7	210
Almond	451	2.6	75

Two states, California and Florida, use more than three-quarters of pre-plant MB in the United States. Although MB is used on over 35 fruit, vegetable and nut crops in California, almost 70% is used for pre-plant treatment for strawberries, seed beds and nursery crops. Florida uses MB primarily on tomatoes, peppers, strawberries, eggplant, watermelon and in its double cropping systems. California's use has decreased 31.2% from 6,571 tonnes in 1991 to 4,522 tonnes in 2000; Florida's use has decreased 26.3% from 6,139 tonnes in 1990 to 4,522 tonnes in 2000 (CAPDR 1991, 2000, EPA 2001, NASS 2001). The use of metam sodium has almost tripled in California since 1990 – some of this increase was due to California prohibiting the use of 1,3-dichloropropene (1,3-D). Use of 1,3-D has increased dramatically since its reintroduction in 1994 and metam sodium use has decreased slightly (EPA 2001).

Previous economic impact analyses have been conducted examining the effect of an outright ban. In 1993, USDA's National Agricultural Pesticide Impact Assessment Program (NAPIAP) found the annual U.S. losses were $1.3 to $1.5 billion a year. Sunding *et al.* (1993) estimated California agriculture's losses to be $162 million. Deepak *et al.* (1994) estimated that seven Florida crops' revenues (rather than loss of profits) will decline 54% from $1.144 billion to $524 million. Mexico's revenue is projected to increase by 65%. Carpenter *et al.* (2000) estimated economic losses will be almost $500 million per year for pre-plant uses. Consumers of just 7 crops (cucumbers, eggplants, peppers, squash, strawberries, tomato and watermelons) will lose $158 million per year in consumer surplus as prices increase when yields decline.

To analyze the new phase-out schedule, a value of marginal product approach was employed. Growers are assumed to be using the pest management technology that maximized the per acre net revenues. Switching to another pest management technology would likely alter the per acre yield and costs, and thus net revenues. The value of each pound of MB for annual crops could be computed using the change in net revenue from the price-weighted changes in per acre yields and changes in per acre costs, assuming growers would shift to the next best alternative pest control strategy outlined in Table 2 and Carpenter *et al.* (2000). This value determined the highest-value use of MB and thus which crop/region combination would continue using the chemical as each stage of the phase-out becomes binding, assuming the most efficient allocation of the chemical is employed.[9] For perennial crops, the value of marginal product was calculated similarly using the change in net revenue over time assuming a discount rate of 4 percent for the expected length of the crop's life. Fifty-two crop/region combinations were examined including nurseries, seed beds, and double cropping systems in 6 states (California, Florida, Georgia, North Carolina, South Carolina, Tennessee). Values were computed for four distinct growing regions in California and five regions in Florida. These uses represented approximately 71

[9] *This approach assumes constant prices, which may not be realistic if yield and acreage changes are large. Growers may find that the relative profitability of a crop changes and switch to another crop. Depending on price elasticities, price changes may compensate for some of the decreased yield and/or increased costs following the switch to another fumigant.*

percent of the 1997 use of MB in the United States. Average prices, costs per acre, and yield assumptions can be found in Carpenter *et al.* (2000).

RESULTS

On a per pound basis, California strawberry growers had the highest value for MB ($55/lb) compared to the next best pest control strategy. California premium wine grapes ($54.36/lb), almonds ($47.03/lb) and Florida strawberries ($34.27/lb) also had high values. In the first round of the phase-out, some acreage went out of production due to competition from Mexico and other U.S. growing areas. Some California growers, such as carrot growers, shifted to using the reintroduced 1,3-D. Florida tomato growers decreased use by over 1000 tonnes (27.2%), strawberry growers decreased use by 9.8%, and pepper growers decreased use by 25% in 2000 compared to 1990. California nursery growers reduced use by 277 tonnes (30.7%) and strawberry growers by 139 tonnes (6.8%) in 2000 from 1991 levels. Seed beds increased use by 289 tonnes (103%) in 2000 from its 1991 level. The implicit cost of this 25 percent reduction was $46.5 million annually. The threshold value of marginal product was $7.74/lb. The price of MB rose 103%, from $1.23/lb in 1995 to $2.50/lb in 1999.

Table 2: Best Alternative Pest Control Strategy to MB[1]

Crop	Pest Control Alternative	Yield Loss (%/acre)	Cost Change ($/acre)
Eggplant	Telone C-17 +Napropamide	15%	$23.11
Pepper	Telone C-17 +Napropamide	12.5%	$23.11
Strawberry	Telone C-17 +Napropamide in Florida	21.5%	$448.73 Cent. FL
	Chloropicrin +Vapam in California		$697.50 C. Coast CA
			$597.50 S. Coast CA
Tomato	Telone C-17 +Pebulate in Florida	10.%	$13.36
	Vapam+Pebulate in Dade County, FL	17.5%	-$60.39
	Telone II in California	10%	$0.00
Watermelon (Single/Double crop)	Telone C-17 +Bensulide +Naptalam	15/17.5%	$96.00
Squash (Double crop)	Florida	17.5%	
	Dade County, FL	22.0%	
Cucumber (Double crop)	Florida	17.5%	

[1] Yield and cost change assumptions for perennial, ornamental and nursery crops were also based on Carpenter, Gianessi, and Lynch (2000).

The 50 percent reduction was also accompanied by a significant increase (80% from 1999; 270% since 1995) in price for MB to $4.50/lb. The additional reduction increased the implicit loss to $114 million, an increase of $67 million. The threshold value of marginal product was $9.51/lb. The next phase-out level of 70% will impose an additional $81.9 million in losses, bringing the total cost to $195.9 million. The threshold value of marginal product was $15.09/lb. If the price increase follows the same trend, the 58.7% increase in the threshold value should result in a 205% increase in the price of MB to $9.23/lb. The largest losses from the phase-out occur with the reduction of the last 30 percent. This additional reduction imposes a cost of $427.8 million, bringing the total cost of the elimination of MB to $623.6 million per year. These last 4305 tonnes have values of marginal product ranging from $15.11 for Central Florida’s double cropping system of tomatoes/cucumbers to $55.07 for California’s South Coast strawberries. If these crop/region combinations qualify for critical use exemptions until more economical alternatives are found, the annual economic impact will be lower. In addition, strawberry prices may increase following a 21.5% reduction in yields, which will decrease the economic hardship to growers but impose costs on consumers.

TABLE 3: Economic Impacts of Phase-out

Percent Reduction	Range of Value ($) of Marginal Product per pound of methyl bromide	Incremental Cost ($)	Total Annual Cost ($)
25% (1999)	1.90 - 7.74	46,535,8	46,535,812
50% (2001)	7.81 - 9.51	67,412,3	113,948,143
70% (2003)	9.70 - 15.09	81,906,1	195,854,327
100% (2005)	15.11 - 55.07	427,764,41	623,618,741

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THE ECONOMIC IMPACT OF THE PHASE OUT OF METHYL BROMIDE ON HORTICULTURAL PRODUCERS IN HUNGARY

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ABSTRACT

Horticulture and mainly vegetable growing is a very important sector of Hungarian Agriculture, especially if export is considered. Szentes contains the largest agricultural area in the world that produces crops year-round using thermal energy from natural underground water supplies. The most important vegetable crops are white-yellow sweet paprika, tomatoes, Chinese cabbage and other brassicas, hot green paprika (pepperoni) and cucumber. Methyl bromide (MB) has been used to control soil borne pathogens in vegetables, mainly nematodes under glasshouses and heated plastic tunnels, and in few cases under non-heated plastic tunnels, since its registration in the mid 1980's. Approximately 27 tonnes of MB are used in Hungary. The tobacco industry eliminated its use of MB in 1999 when it adopted the floating bed technology for rearing seedlings. Rockwool combined with grafted plants offers the best promise for eliminating the remaining uses of MB in this sector by 2005.

Keywords: economic impact, phase out, geothermal energy, Hungary

INTRODUCTION

Árpád Company, founded in 1960 as a Vegetable Growing Co-operative, is one of the top Hungarian agriculture companies. The company first produced open-air crops and later crops grown under glass and plastic. Today Árpád is no longer a cooperative as for political and economical reasons the company was changed to an Incorporated Share Company in 1999 with a founding capital of about € 11 million. Árpád has about 1 200 shareholders (majority of them previous coop members), but 70-80 shareholders could make the important decisions as they have more then 50% majority.

Szentes in Hungary and the surrounding area has a tradition in vegetable production going back centuries. Gardeners from the present Bulgaria immigrated to Hungary in 18th century and established a new method of vegetable production with intensive irrigation between the rows. They also brought with them their new types of vegetables not previously grown in Hungary. These gardeners delivered their products not only in towns in Hungary but delivered as far as Vienna.

The Bulgarian gardeners settled in the Szentes area because of the good quality soil and irrigation water from nearby rivers and irrigation canals. Sunshine hours equate to more than 2 050 hours per year. Geothermal energy was also abundant locally which enabled vegetable production throughout the year under glass and plastic. Szentes developed in the 1960's and 1970's as, during this period, thermal wells were drilled and used for heating greenhouses. It is unambiguous – that despite the continuously growing energy costs and taxes – only the geothermal energy made it possible for large-scale, profitable vegetable production under glass and plastic. Today, 14 thermal wells are operational sourcing hot water from average depth of 2 000 m at a temperature 78-96ºC and a flow of 60-70 m^3/hour.

PRODUCTION AND MARKETING

Thermal water is used to heat 46 hectares of glasshouses and plastic tunnels, as well as animal farms, a grain drier and social buildings. This is the world's largest agrarian project heated only with geothermal energy. More than 500 families are growing vegetables – with the technical assistance of our horticultural engineers - using 23 ha glasshouses, 23 ha of heated plastic tunnels, 40 ha of non-heated plastic tunnels and on 50 ha in the open air. The total amount produced is around 10 000 tonnes a year for a turnover of about € 6.7 million.

Crops

Árpád's most important crop is the white-yellow sweet paprika (cone shaped). The varieties are mainly Hungarian hybrids. This paprika is grown and sold each day of the year and is produced under glass, heated plastic, and non-heated plastic tunnels. Professor Szent-Györgyi Albert won the Nobel Prize in 1937 for synthesising vitaman C from paprika grown in nearby Szentes and Szeged.

The next important crop is the tomato, which is grown under glass (spring and autumn) and under heated plastic tunnels. The varieties are the different Dutch varieties. On smaller acreages, hot green paprika (pepperoni) and cucumber are produced in glasshouses.

The typical main crop under non-heated plastic is the yellow sweet paprika. As early spring crops Chinese cabbage and other Brassicas are produced which are harvested in April and May. In the open air (partly covered by a plastic layer), Chinese cabbage and other Brassicas, Onion, Spice Paprika for milling are also produced.

Árpád has a well-trained, effective plant protection and production technology Advisory Service Team which helps Árpád to integrate the small individual growers. Altogether some 1,500 to 2,000 small producers are integrated in this way.

Certification

The Company Det Norske Veritas certified our vegetable production and sales according the ISO 9002 Standard in 1998. HACCP certification is also under preparation (it has been completed for Chinese cabbage and paprika). We also started to build up the ISO 14000 Standard for our horticulture production and sales and an audit is planned for February 2002.

Coolstores

Árpád has coolstores where products are prepared for shipment for the home market or for export. One of the coolstores was modernised in 2000 and follows the newest EC standards of environmental friendliness.

Exports

The products of Árpád and products sold through the integration with other companies are well known in Germany, Scandinavia, Slowenia, Slovakia, Czech Republic and Austria. The number 1 export article is the yellow paprika. This product has the right to use the common Hungarian brand: “Quality Food from Hungary”. From our total turnover of € 6.7 million, about 30-40% is derived from exports and the remainder from the home market. Products of other companies can also be coolstored by Árpád.

Integrated Pest Management

Árpád started an Integrated Pest Management Programme several years ago to address the requirements of customers abroad and in Hungary who were more interested in healthy products free from chemicals.

Bumblebees are used for better pollination and beneficials to control the different harmful insects. Árpád is a distributor with exclusive rights for a Belgian company on this field.

In 2000, the operation was so successful that no chemical treatment was needed at all in some of Árpád’s glasshouses involved in the project. In 2001 the start was not as easy as too many insects survived the mild winter, so sprays had to be used against thrips and other insects.

METHYL BROMIDE USE AND PHASE OUT

Methyl bromide

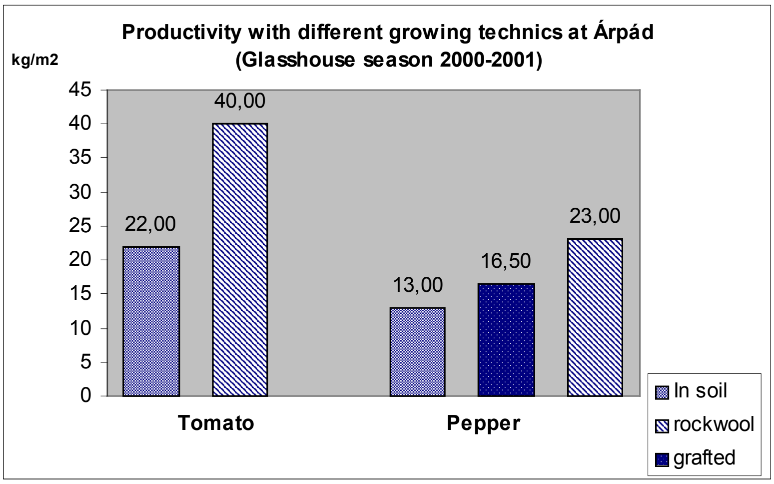
There were more and more problems with soilborne pests and diseases, especially with nematodes and thrips, as Árpád had old production facilities and a monoculture type of growing. Árpád was one of the first companies in Hungary to obtain the right to use MB in the mid-1980’s for desinfection of soil in greenhouses. Árpád has well-trained personnel to fumigate safely and equipment to distribute the gas.

During the years of monopolised foreign trading Árpád bought MB from Chemolimpex Foreign Trading Company. After the political and economical changes, Árpád applied to the Ministries of Agriculture, Environment Protection and Foreign Trading to import MB directly which resulted in cheaper MB. Zephyr Ltd. and the tobacco industry have also obtained licences for importing but today only ÁRPÁD and Zephyr require the use of MB which is 27 tonnes per year.

Substrates for production

As Árpád became aware of the Montreal Protocol and its phase out requirements for MB, it started to modernise its greenhouses to allow for soilless rockwool technology. In 1998, a pilot glasshouse of 3,600 m^2 was prepared to grow tomato on rockwool. As the results were good Árpád increased the area of tomato in 1999 to 1ha. In 2000, paprika was grown for the first time on rockwool on 2 ha. and expanded to 6 ha in cooperation with the Ministry of the Netherlands in 2001. In 2002, a further 4 ha investment using rockwool was completed consisting of 2 ha paprika, 1 ha tomato and 1 ha cucumber. Currently, 11 ha of rockwool is in production and Árpád plans to increase this further. Of course, the investment costs and support for modernising such an old operations have determined the speed with which MB could be eliminated (see data in Table 1 and Figure 1).

Figure 1: Productivity with different growing techniques at Árpád.



Grafted plants

The heated plastic tunnel units were too small with little air space, uneven heating and had problems with irrigation water quality requiring filters. These factors made production on rockwool very difficult. Grafted plants seemed to offer a way to overcome these limitations.

The first trials were made in 2000 using grafted paprika culture under heated plastic. Grafted plants were bought from Italy. The root plant was Snooker and the producing plants were traditional varieties. The much stronger and bigger root mass supplied the upper producing plants with more water, feed and minerals. The stronger crop was more resistant to stress and to any disease, virus, and bacteria. The larger root was more tolerant of nematodes and consequently a much larger leaf mass was developed with larger yields. To save costs, the bigger roots allowed the use of two main stems rather than one in the traditional growing method.

The Regional Demonstration Project conducted in Poland, with the help of UNEP, could provide alternative chemicals and growing techniques. Grafted paprikas combined with some chemical treatments could bring good results under non-heated plastic tunnels. Possibly all greenhouses will be equipped with rockwool by 2005 allowing the elimination of MB at this time.

Information transfer

Árpád has organised each year at least two workshop days - one in Spring and the other in Autumn. Growers are invited from all over Hungary. Specialists from abroad make presentations. In 2001 the subjects were: “Soilless paprika growing under greenhouses and the new technology with the grafted plants”. Árpád also has a newsletter sent to all growers involved in production. Árpád specialists write articles for the growers in various periodicals such as “Horticulture and Vinary”, “Plant protection”, and “Hungarian Agriculture”.

Costs

Table 1 is summarises the results of the new techniques. The operating costs were higher on rockwool and with grafted plants, but it was still profitable. Investments costs can be recovered in a maximum of 4-5 years.

Table 1: Summary of economic impact Comparison of yields, incomes of different cultures and growing methods (Glasshouse season 2000-2001)

CRITERIA	TOMATO		PEPPER		
	In soil	Rockwool	In soil	Grafted	Rockwool
Yield kg/m^2	22[1]	40	12-13[2]	16,5	22-23
Income Ft/m^2	3 800	6 000	2 800	3 700	6 000
Mbr cost Ft/m^2	190	-	190	190	-
Investment costs Ft/m^2 [3]	-	5 000	-	-	5 000

[1]Tomato in soil 2 crops spring and automn; [2]One spring crop only; [3]Investment costs include: Soil removal 5 000 m^3/ha, in order to increase the possible height of the crop; Change of old isolation, broken glasses; New heating system; New drip irrigation system; New irrigation water cleaning system; New irrigation water distribution system. 1 EUR = 239.605 Hungary Forints in February 2002.

It was difficult to make economic analyses about the private plastic growing units because:

- Ownership changed and no data were available;
- Different heating possibilities, consequently different planting periods, different cultures, different harvest results, and incomes;
- Different inputs;
- The level of integration differed; and
- Lack of any state subsidies.

Despite these facts, I am sure that Árpád’s growers will find the optimal solutions for themselves to survive after Hungary joins the European Community. I am confident that growers could carry on a profitable production, even to develop their production facilities and growing techniques and do well without MB.

ECONOMIC EVALUATION OF METHYL BROMIDE ALTERNATIVES USED ON THE EAST COAST OF SPAIN

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ABSTRACT

Growers need alternatives to MB that are safe, consistent and cost-effective. Several projects were undertaken in the Mediterranean coast of Spain (Valencia and Murcia) to evaluate the cost of products and techniques tested as alternatives to methyl bromide (MB) on crops such as citrus, open-air horticulture, strawberry, and greenhouse-grown pepper.Telone (1,3-dichloropropene with chloropicrin) gave the most consistent and reliable results. There is interest in solarization, particularly when combined with chemical or biofumigants at low dose, however, in greenhouse-grown peppers have other costs associated with reducing the harvesting period. The use of grafted plants is a solution for watermelon and offers possibilities in other species. To compensate for possible increased costs for alternatives, Integrated Crop Production can be a solution as this adds value in some markets.

Keywords: Horticultural crops, chemical alternatives, solarization, grafted plants, integrated crop production.

INTRODUCTION

The favourable climatic conditions on the East of Spain and its proximity to the European markets has proven attractive to the horticultural industry. Horticultural production has expanded and competition has increased. The structural and economic change of the horticulture has been spectacular and the evolution in production methods has led to greater specialisation. Greenhouse production and other intensive cultivation techniques have increased in most arid provinces due to the advantages of stable climate and sunlight. One of the consequences of this specialisation is a trend towards monoculture, intensification of the use of the soil and the disappearance or reduction in rotation crops.

Monoculture is a consequence of the internal economies of production and of other externally-derived factors driven by the market place. Repeated cultivation on the same land has forced growers to disinfect soils of a range of pathogens (see Cebolla 2001; Katan 2000) using methyl bromide (MB) for crop production security.

The elimination of MB has required us to intensify the research and development of alternatives. Among the studies that are being carried out in Spain, INIA SC97-130 and the projects IVIA-5706 and IVIA-5012 are some of the most important. As part of these studies, we report here the viability and cost of several alternatives to MB. Added to this analyis is a section on Integrated Crop Production (ICP) and how its introduction affects soil disinfestation.

CULTURES AND TREATMENTS

Soil disinfestation using MB is carried out on commercial production properties in the East coast of Spain when re-planting citrus (infrequent MB application); in horticultural crops (necessary occasionally); in strawberries crops (very often); and in greenhouse-grown pepper (essential). These four groups were introduced into the Work Plan in order to find alternatives to MB prior to the ban on its use.

An economic evaluation was perfomed on the results in the technical reports taking into account: 1) The total costs of every treatment (product and application); 2) The cost-benefit obtained from the treatments due to sales in the market; and 3) Risk of crop loss or reduction in yield. We also took into account the external costs such as the type of alternative, its impact on the ecosystem and its benefit to society, the difficulty of applying the alternative and the possibility of adoption by growers.

Citrus

The trees killed by tristeza virus are replanted on the same land. Disinfestation with MB is carried out to avoid problems with a number of disease problems including Phytopthora and soil sickness (non-specific replant disease). The treatments also aim to increase production. Zaragoza *et al.* (2001) used nine treatments to measure the development of the trees and the productions over three consecutive years (1999, 2000 and 2001). From this information, it was possible to say that :

- Non-disinfested land did not induce more tree deaths than disinfested land;
- Tree vigour in disinfested plots was not reflected in increased income, especially if the soil disinfestation was delayed for more than one year ; and
- The lost income when planting was delayed one year was less than the disinfestation cost.

It was difficult to be definitive as different species of nematodes or fungi may make disinfestation more worthwhile. Citrus work will continue and the results will undergo further economic analysis.

When the plot is registered in ICP there are regional regulations that prohibit the use of chemical disinfecting.

Open-air horticulture

Agrarian systems are important with typical crop rotation under intensive production, up to three harvests per year. As an example, the production of the earth almond *Cyperus sculentus* is one of the most important. The use of MB in this crop is required to control unknown diseases localised in the soil due mainly to repeated cultivation on the same land and to control a remainder *Cyperus sculentus* crop that is difficult to eliminate after harvesting and becomes a weed. Cebolla *et al.* (2000) showed the effects of the MB and four alternative treatments, based on INIA project SC 97-130 and IVIA 5706.

From the economic viewpoint, there are suitable alternatives to MB using, for example, solarization combined with manure or metam sodium at lower doses, or Telone combined with metam sodium or chloropicrin. MB was best at weed control and its use in this area could be relatively low. Notably, each alternative gave a number of problems suggesting more experimental information will be required before MB can be eliminated. The profit from each of these crops is minimal and severely restricts the choice of alternative.

Grafted watermelon was an example of a successful alternative to MB which has been accepted on a commercial scale. Repeated growing of grafted watermelon on the same land did not produce any negative effects. Grafted watermelon was 798.34 euros per hectare cheaper than MB disinfestation.

Strawberry

Production area has declined in Valencia because the expansion in Andalucia. The farms remaining in Valencia are mostly operated by families. MB disinfestation is reported to improve quality and consistency of production. The data have been analysed from a technical perspective (Cebolla *et al.* 1999) and from an economic perspective (Caballero *et al.* 2000). For two growing periods and based on a sound statistical design, eight treatments were investigated which included a non-disinfested (control), two MB treatments and other five alternative treatments. Proportional indexes were developed taking as a base 100 the traditional treatment of MB-60.

In the first year, solarization combined with manure (6 kg/m^2) and metam-sodium gave yields similar to MB, but these results were not repeated in the second year. Traditional MB and MB at half dose with plastic VIF gave similar results. Metam-sodium without solarization resulted in lower yields. Biofumigation with high doses of manure gave inferior yields in both years to the non-treated control.

Once the yield from the different treatments had been compared, other factors were considered such as the costs of the treatments, prices in the market, and the cost of applying the alternative in order to build a representative economic model of the productive system in the Region.

The results show that profit margins are very narrow and a minimum yield is required in order to recoup the high capital costs of disinfestation, acquisition of plants and hand labour. Given the high proportion of the variable costs, the differences in the costs of disinfestation among the treatments did not allow us to produce decisive economic analyses. However, disinfestation only when required is an option that farmers will need to consider in the future in order to avoid production costs that cannot be recovered.

Greenhouse-grown peppers

This crop has the greatest dependence on MB. Alternatives examined include MB with and without VIF, solarization combined with manure, chemical products at lower doses, and use of grafted plants. The results have been reported under project INIA SC-97 130 which included the Campo de Cartagena (Murcia) and the Co-operative SURINVER of Pilar de la Horadada (Alicante).

Data were collected over several harvest and indices established allowing comparison between MB and non-MB treatments. Weekly cash flows based on market prices to the co-operatives permitted an evaluation of the cost-effectiveness of the different treatments.

From the alternatives studied, the best was 1,3-dichloropropene and chloropicrin (Telone C-35) which had profits similar to MB and, in some cases, superior. Solarization reduced the doses of other products used in combination but it was difficult to get the same results across several growing periods. In the first place, the yield was lower than that obtained with Telone C-35. In addition, there was a yield decline of 20-24% due to the lack of production in August and September. The overall decline in income was 11-15% using solarization. It is necessary to take into account that all the expenses, except harvesting, have already been done and the fixed costs are the same for the whole year.

This procedure can result, very useful, in the years in which at the first of August could have finalised the productive life of the crop because of virus or other causes. Solarization is a good basis on which to promote ICP.

The economic evaluation of one plot with grafted plants showed that the method appeared promising despite yield and profit being less than those obtained with MB and Telone-C35. Grafting is also a good basis on which to promote ICP.

Greenpepper production using substrates accounts for 10% of production with the potential to increase further when high-quality water is present and growers are technically competent. Yield is usually 40% more, and current prices 25% more, than greenpeppers produced in the soil.

INTEGRATED CROP PRODUCTION

Efficient production is countered by consumers who are preoccupied by product quality, pesticide residues and environmental damage. ICP attempts to address consumer concerns by being based on ecological production, sustainable agriculture and and economically viable treatment methods. ICP calls for the rational use of inputs, regulation of agrosystems, sale of a competitive product and security of food supply. Soil disinfestation, common in intensive production, is one of the cultural practices most limited by the ICP.

ICP envisages the use of all the possible methods in intensive, horticultural production. The regulations can include chemical disinfection as long is this is justified and authorized. It is recommended in the regulations that chemical disinfestation should not occur over the same plot in two consecutive years.

The reduction of residues in the product favours its sale for good prices that can compensate for moderate increases in the costs of production and in the near future, the commercial quality will be guaranteed with traceability from plot to market. ICP products have greater acceptability and can be commercialised within the normatives EUREP-GAP. The members of EUREP represent in Europe one important part of the large surfaces. ICP is the best instrument for a holistic cultural practice and the results submitted to the laws of supply and demand in the market place.

CONCLUSIONS

Viable alternatives have been found for MB but with limitations and differences for security of production. Despite some application problems, various combinations of Telone (1,3-dichloropropene) with chloropicrin have been shown to be safe and consistent with an economic impact similar to MB. Solarization gives better pathogen control when combined with chemical disinfectants at low doses or with manure, and economically this is effective too. Solarisation in glasshouse-grown peppers is acceptable for ICP but production should cease after the first days in August, with economic repercussions, having to do without the harvests in August and September.

Grafted watermelon is a viable alternative. Grafted tomatoes and melons remain possibilities for the future. Grafted pepper appears very interesting for the future, especially in ICP. Telone C-35 currently provides the grower with a secure, chemical alternative with the best results.

MB set an internal economy for pest control on the farm. Regulatory restrictions cause economic diseconomies. One solution to avoid higher costs could be the massive introduction of the ICP, as this will enable farmers to get higher market prices, which will help to compensate for the costs of the alternatives.

Combinations of alternatives can reduce the secondary effects and the external costs, even those growers using small amounts MB when it is not eliminated totally. On the other hand, it is not absolutely convenient to base an economic activity on a production factor that is difficult to substitute such as MB with his future elimination (Katan, 2000).

It is possible to increase considerably crop production using substrates without expanding the total area.

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SOUTHWESTERN SPAIN STRAWBERRY GROWERS AWARENESS OF THE METHYL BROMIDE PHASE OUT AND THEIR WILLINGNESS TO PAY FOR ALTERNATIVES

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INTRODUCTION

The ban in the immediate future on the use of methyl bromide (MB) in soil disinfection may cause a short-to-medium term increase in production costs for some farmers. Farmers most affected in Spain are those producing strawberries, cut flowers and nursery crops and, to a lesser extent, plastic covered horticulture producers. This paper reports on the results of a survey carried out on more than 500 strawberry growers in south-western Spain to analyse their situations, attitudes and willingness to pay (WTP) for a hypothetical MB alternative of similar disinfecting powers. The study identifies the factors which determine the WTP.

METHODOLOGY

A survey was carried out on 504 strawberry producers in the area of Huelva (south-western Spain). The questionnaire used contained questions on the structure of the farms, aspects concerning the adoption of innovations and management, sociocultural characteristics of the grower, soil disinfection procedures, and their willingness to pay (WTP) for a hypothetical alternative to MB.

Two Probit Binomial and Multinomial Ordered Dependent Variable Models were used to identify the factors determining both the fact of having or not WTP, and the amount to be payed. The same explanatory variables have been considered for the two models as follows: S: Farm Surface; AI: Attitude towards Innovation; IPA: Integrated Production Acquaintance; AS: Attendance to Seminars on methyl bromide; YF: Years as a Farmer; FA: Formation (formal studies) in Agriculture; VI: Technical visits to other areas in Spain or abroad; LA: Reads technical Literature (books) on Agriculture; and A: Age of grower

RESULTS

Attitudes and opinions of growers

Figure 1-a shows the distribution of chemicals that have been used in the area to disinfect the soil. We see a prevalence of MB used only in beds. By observing the current distribution in Figure 1b it becomes clear that this is a growing trend to the detriment of all surface MB and of metam-sodium disinfection.

As far as dosage is concerned, Table 1 shows that, at present, the prevailing quantity of MB only beds is of 200 Kg/ha. When applied to all surface, the dosage rises to 350-400 Kg/ha. Table 2 shows the self-evaluation of results of the three technologies most often used: in view of this self-evaluation (B: bad, V.G: very good) it is easy to understand why the use of MB is favoured, and also that the treatment only in beds is on the increase, since it only requires approximately one half of the dosage used on all surface, and the two distributions of results frequency do not differ significantly ($\alpha \geq 0.01$).

Almost all (97.62%) strawberry producers use MB as soil disinfectant, and most of them (86.71%) consider the ban on MB a serious problem that is going to harm their business. Only 6.55% are confident that an equivalent alternative treatment will be available soon. However, the majority (94.98%) express their unwillingness to stop growing strawberries, even if they have to discontinue MB use.

Of the criteria influencing their decisions on which disinfecting techniques farmers intend to adopt, the environmental impact was a criterion of little importance to producers. The main factors important to farmers were, in order of priority, yield and the commercial quality of the fruit (Table 3). Almost all farmers (98.41%) believed that soil disinfection was indispensable for ensuring steady production. Most (92.7%) farmers thought that, in the case of strawberries, there were currently no alternative technologies to MB with similar disinfecting power. Most farmers believed (82.25%) that MB harmed the ozone layer and, moreover, most (82.67%) thought that it was noxious to the operator applying it. At the same time farmers agreed (95%) that MB improved strawberry quality.

Willingness to pay for an alternative to methyl bromide

In relation to the willingness of farmers to take on additional per-hectare cost for having a MB alternative of similar disinfecting power but harmless to the ozone layer, 72.62% of the farmers presented a positive WTP, while the rest (27.38%) were not willing to pay more. Those not willing to pay more thought that it was not worth the extra cost if production was not increased (15.95% of the farmers), they would like the alternative but they could not afford to pay more (9.03%) or that society should pay as this was an environmental issue (2.4%). The "protest answers" represented only 2.4% of the total farmers which could be interpreted as an implicit acceptance of their responsibility by 97.6% of farmers to eliminate MB. The remaining reasons for not showing a WTP were related mainly to profitability.

Distribution figures for the 72.62% of farmers who show WTP can be seen in the Figure 2. Average value is 342 (341.75) euros/ha and its variation coefficient is 0.59, the highest value being 1200 euros/ha and the lowest 60 euros/ha (apart from zero values). The data show that 61% of the values are between 240 and 360 euros/ha.

WTP value includes in this case two value components that are not easily separable. On the one hand, producers' interest in seeing themselves free of a problem posed by the use of MB which they know is going to be banned and, on the other hand, their awareness of the damage they cause. In any case, it is clear that the main component of the value represented by the WTP is the MB ban since minimising environmental damage did not constitute an important criterion among most producers.

From the data, the average WTP for all producers would be 248.36 euros/ha which means that an additional cost of this amount would be readily acceptable to the average farmer in the area.

Other exlanatory variables

Results from the binomial Probit model indicate that only S, AI and IPA show a significant correlation to the fact of presenting or not WTP.

With respect to S, a "non-continuous WTP scale effect" was detected. Farm owners who grow more than 8 ha of crops displayed greater probability of having WTP than farmers who produce on a smaller surface scale. Also, farmers who are more prone to adopt innovations once they have analysed their feasibility, and without waiting for most other farmers' successful reports, usually present WTP more frequently. Likewise, farmers acquainted with integrated strawberry production present greater likelihood of having WTP.

Result from multinomial ordered Probit model showed that, within growers with positive WTP, age, attendance at MB alternative seminars and visits to agricultural areas were significantly correlated to WTP. A grower aged between 25 and 35 had the highest WTP values. No significative scale effect ($p \geq 0.95$) was detected. Numerical figures concerning the estimation of the models can be seen in Calatrava (2001).

ACKNOWLEDGEMENTS

The work has been made under the scope of the INIA SC97-130 Lopez-Aranda (1999).

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Table 1: Distribution of dosages (kgs/ha) used for soil disinfection in Huelva strawberry plantations

Methyl bromide (Only beds)		Methyl bromide (all surface)		Metam-Sodium (Different ways)	
KGS/HA	**%**	**KGS/HA**	**%**	**KGS/HA**	**%**
100	1.04	150	1.0	100	10.52
150	9.66	200	1.0	400	31.57
200	77.56	250	2.0	500	15.80
225	0.26	300	5.0	667	5.26
250	6.26	350	31.0	700	15.80
300	1.56	359	1.0	833	15.80
350	1.30	375	1.0	1000	5.26
400	1.30	400	53.0		
450	0.53	450	4.0		
500	0.53	500	1.0		

Source: Project SC97-130

Table 2: Self-evaluation of results of technologies for soils disinfection most often used in Huelva strawberry plantations

Self-evaluation of Results	Methyl Bromide (only beds)	Methyl Bromide (all surface)	Metam-Sodium (different ways)
Very Good	60.57	69.00	--
Good	33.42	28.00	57.89
Bad	5.48	3.00	26.31
Very Bad	0.53	--	5.26

Source: Project SC97-130

Table 3: Assessment of the importance of criteria (0=Not important, 5=Very important) in the choice of soil disinfectant techniques (% of growers).

Criterion/Score	0	1	2	3	4	5
Greater production	-	0.60	1.98	14.68	30.95	51.79
Higher commercial quality of the fruit	0.20	0.99	6.76	28.97	40.28	22.82
Diseases reduction	0.40	12.50	19.84	26.39	19.25	21.63
Lower treatment cost	17.86	9.72	42.46	20.44	6.55	2.98
Fewer residues	4.76	58.73	24.80	8.53	2.78	0.40
Lower environmental impact	76.79	14.46	4.37	0.79	0.20	0.40

Source: Project SC97-130

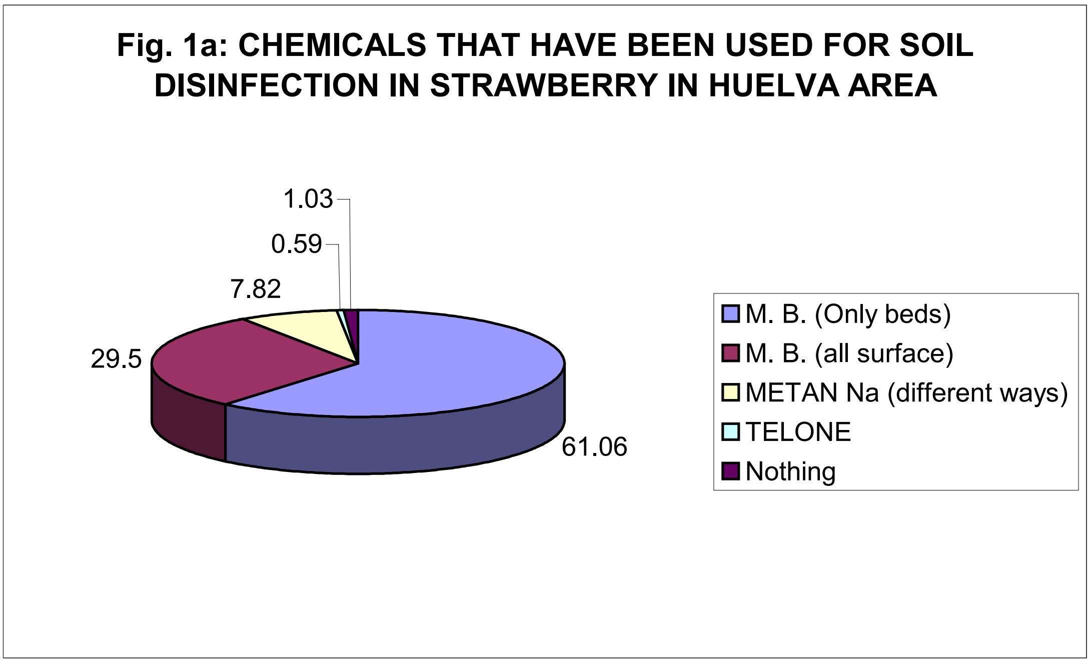
Fig. 1a: CHEMICALS THAT HAVE BEEN USED FOR SOIL DISINFECTION IN STRAWBERRY IN HUELVA AREA
1.03
0.59
7.82
29.5
61.06
M. B. (Only beds)
M. B. (all surface)
METAN Na (different ways)
TELONE
Nothing

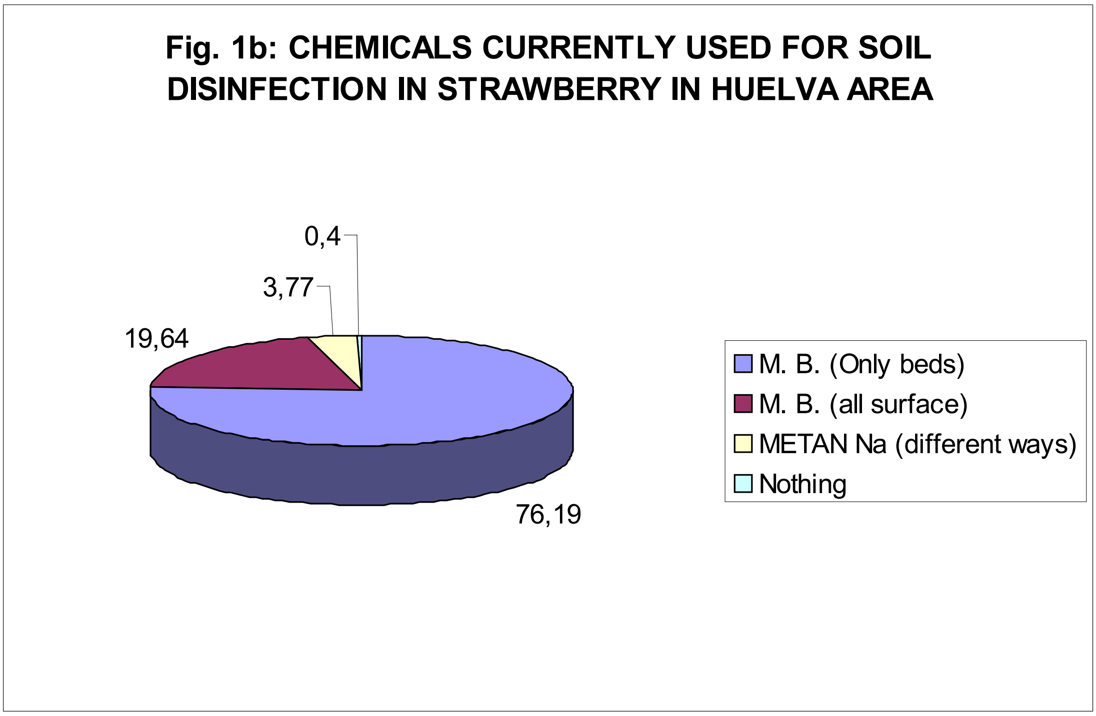
Fig. 1b: CHEMICALS CURRENTLY USED FOR SOIL DISINFECTION IN STRAWBERRY IN HUELVA AREA
0,4
3,77
19,64
76,19
M. B. (Only beds)
M. B. (all surface)
METAN Na (different ways)
Nothing

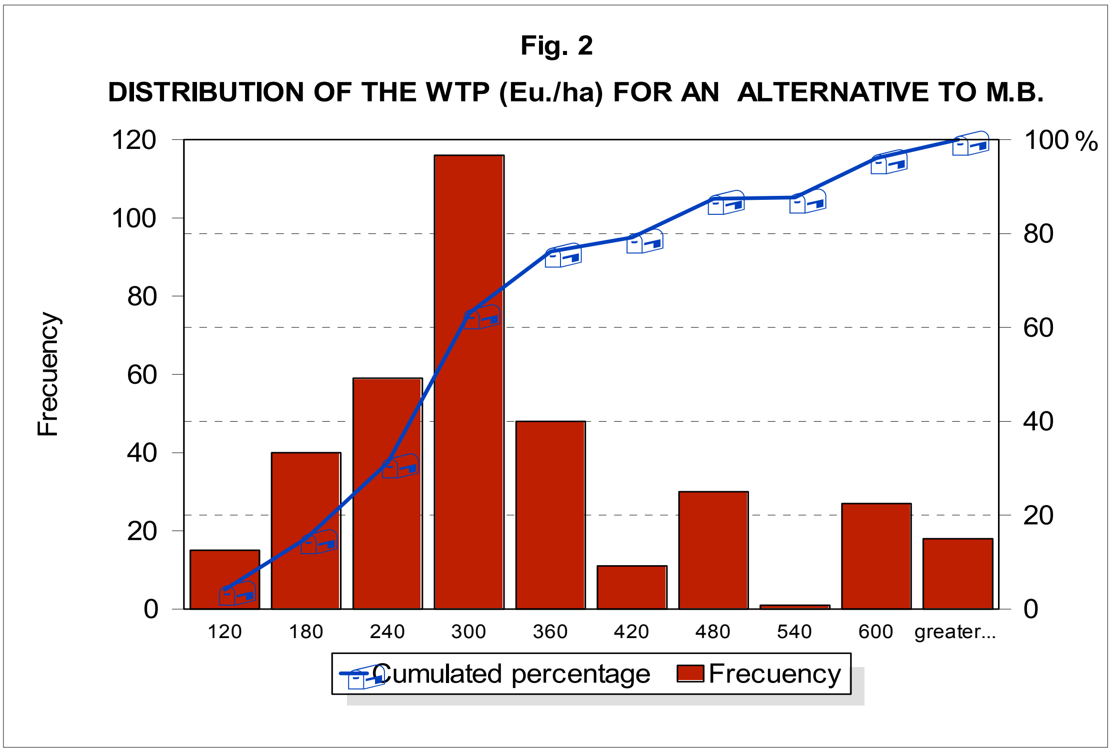

Fig. 2
DISTRIBUTION OF THE WTP (Eu./ha) FOR AN ALTERNATIVE TO M.B.
Frecuency
120
100
80
60
40
20
0
100 %
80
60
40
20
0
120
180
240
300
360
420
480
540
600
greater...
Cumulated percentage
Frecuency

"EUREPGAP" STANDARDS - PROMOTING SAFE AND SUSTAINABLE AGRICULTURE INCLUDING ALTERNATIVES TO METHYL BROMIDE

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ABSTRACT

EUREPGAP provides global agricultural production standards and a verification framework for fruit and vegetables to retailer and supplier members. A "Steering Committee" and a "Technical & Standard Committee Fruit and Vegetable" undertake a continuous review of supporting documents and procedures. Certifiers accreditation to ISO standards based on "EUREPGAP Fruit and Vegetables" has recently been achieved. EUREPGAP requires written evidence from growers for the use of soil fumigants such as methyl bromide (MB) including information on the location, date, active ingredient, doses, method of application and operator. EUREPGAP recommends a grower demonstrate to the certifier that alternatives to MB have been explored by showing their technical knowledge and written evidence of alternatives to soil fumigation. EUREPGAP requires chemical fumigation of soils to be justified and used only as a last resort. EUREPGAP recommends alternatives to MB such as crop rotation, planting of break crops, use of disease resistant cultivars, solarization, conversion to soil-free cultivation and similar techniques. EUREPGAP "Recommendations" are currently voluntary but may become compulsory in the future.

INTRODUCTION

The Euro-Retailer Produce Working Group (EUREP) started as an initiative by retailers in 1997. The current version of the EUREPGAP document and procedures has been agreed among partners in the entire food chain for fruits and vegetables after wide consultation over three years. More than 700 people from more than 35 countries world-wide attended the annual EUREPGAP conferences in 1999, 2000 and 2001. Technical input from certification bodies concerned with compliance criteria combined with practical experience from field trials in more than one country were used to shape EUREPGAP. During this process, all developmental versions were made public on the EUREP website.

The normative document for certification, "EUREPGAP Fruit and Vegetables", has been developed from a European group of representatives involved in all stages of the fruit and vegetable sector with support from producer organisations outside the European Community.

The EHI-EuroHandelsinstitut e.V., a non-profit making, private research and education institute in Cologne, Germany, acted as international secretariat in the construction phase of EUREP until February 2001. From March 2001, EHI founded the independent daughter company FOODPLUS GmbH that acts as independent global body, hosts the EUREP Secretariat and serves as legal owner of the normative document. EHI's non-profit status is guaranteed by the Steering Committee that oversees the budget.

In January 2001, all retailer and supplier members of EUREPGAP set-up a formalised, representative decision making structure. A "Steering Committee" and a "Technical and Standard Committee Fruit and Vegetable" were created and given the responsibility for continuously reviewing documents and procedures.

RESULTS

Today, there are local offices of certification bodies in more than 25 countries world-wide. The first group of certifiers achieved internationally-accepted accreditation to ISO Guide 65/EN 45011, based on compliance criteria contained in "EUREPGAP Fruit and Vegetables".

The prospect for growth of EUREPGAP by providing an international verification framework for a wide range of agricultural production sectors is, by any estimation, quite outstanding. EUREPGAP is considered to be in the pole position to become the global player in agricultural production standards and verification framework for fruit and vegetables. Retailers are resourcing globally and are facing increasing competition, there is pressure on profitability and an ever-tightening regulatory environment. Food safety has lately become a top priority for many retailers. At the same time, producer organisations from all continents have applied to EUREPGAP for membership as they seek integrated and cost effective solutions for delivering assurance on food safety and environmental issues.

FOODPLUS/EUREPGAP is faced with the exciting opportunity of developing a global integrity and harmonisation programme, a task that can only be successful with a strong and harmonised support of a European and ultimately a global accreditation system.

METHYL BROMIDE

"The EUREPGAP protocol Fruit and Vegetables" provides transparency on the compliance criteria for methyl bromide (MB) whose use must be justified and recorded. Any partner in the food chain can demand information on whether MB has been used or not and take this into consideration in the purchasing decision. The independent certification assures the information. Via this transparency, EUREPGAP intends to discourage the use of MB in a voluntary way. The recommendations are recorded by an independent certifier. Note that "Recommendations" are currently voluntary but may become compulsory in the future.

Excerpt from Protocol Version September 2001:

Requirement	**Recommendation**
5.d. Soil Fumigation:	
#1 Chemical fumigation of soils must be justified.	**#2**. Alternatives such as crop rotation, planting of break crops, use of disease resistant cultivars, solarization, conversion to soil-free cultivation, and similar techniques must be explored before resorting to use of chemical fumigants

Excerpt from Control Points and Compliance Criteria Version September 2001:

Requirement	**Compliance Criteria**
5.d. Soil Fumigation:	
#1 Is there a written justification for the use of soil fumigants?	There is written evidence for the use of soil fumigants including location, date, active ingredient, doses, method of application and operator.

Recommendation	**Compliance Criteria**
5.d. Soil Fumigation:	
#2 Have alternatives to chemical fumigation been explored before resorting to use of chemical fumigants.	The grower should be able to demonstrate assessment of alternatives to soil fumigation through technical knowledge, written evidence or accepted local practice.

Recommendation	**Compliance Criteria**
13 Environmental Issues – impact on farming environment	
#1.1 Does the grower understand and assess the impact his farming activities have on the environment?	The grower is able to demonstrate his knowledge and competence in regard to minimising the potential negative impact of the farm activity on the local environment.
#1.2 Has the grower considered how he can enhance the environment for the benefit of the local community and flora and fauna?	There are tangible actions and initiatives that can be demonstrated by the grower either on farm or by participation in a group that is active in environmental support schemes.

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More information on the EUREPGAP programme can be obtained on the website www.eurep.org .

COMMERCIAL POLICIES IN SPAIN INFLUENCING THE USE OF METHYL BROMIDE BY GROWERS

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ABSTRACT

The Association of Harvesters and Exporters of Fruit and Vegetables in Almería (COEXPHAL) has had 25 years of experience in intensive horticulture in the south-eastern part of Spain. Eighty per cent of both producers and exporters in Almería are represented by COEXPHAL. Almería is the area with the highest percentage (70%) of production and export of vegetables in Spain. Growers since 1997 have been requested not to use methyl bromide (MB) and today MB is no longer necessary for production. Alternatives have replaced MB based on a new agreement on the appropriate measures to be taken reached jointly by COEXPHAL and different chains of supermarkets. Growers must fulfil specific requirements and comply with rules in order to be certified.

Keywords: vegetables, Almería, rules, greenhouses

INTRODUCTION

According to the Ministerio de Agricultura, Pesca y Alimentación (MAPA), methyl bromide (MB) was used to disinfect 1429 hectares in Almería in 1995. Although we are aware of the difficulty finding alternatives to MB to control pathogens, especially in certain places such as Huelva where strawberries are grown, we committed ourselves to the elimination of MB. All the requirements requested by the chains of supermarkets consisting of a programme for integrated production and a new agreement on the appropriate measures to be taken resulted in our efforts being directed toward the achievement of two goals: 1) A healthy product and 2) Grown with respect to the environment. In 1997, COEXPHAL with the "Federación Española de Productores y Exportadores de Frutas y Hortalizas-Spanish Federation of growers and Exporters of Fruit and Vegetables" (FEPEX) and the "Asociación Española de Normalización y Certificación" (AENOR, Spanish Association of Normalisation and Certification) were the driving force behind the creation of a norm of production (UNE 155001).

Since 1997, exporters have been requested not to use MB and it has been successfully replaced by new alternatives which has proved to be to our customers' complete satisfaction. Today, MB is no longer used in this area. Alternatives to control nematodes and pathogens were selected on the basis of successful research (e.g. Bello and Tello 1998). This paper describes rules that we have put in place to meet the requirements of the consumer and the environment. Finally, we discuss the success that we have had with specific alternatives to MB.

CONTROLLED PRODUCTION

Today, the international market requires high quality food produced with strict safety measures without damage to the environment. Norm UNE 155001 applies to growers who are bound to produce and handle fresh vegetables. Thus, growers are directly influenced by commercial policies in Spain. Growers must dismiss the idea of using MB as soon as possible and learn how to implement alternatives.

The consumer of food and agriculture products has become increasingly demanding, so several factors usually have a bearing on the final decision – according to the law of supply and demand. To comply with the consumer's demands, the consumer must be provided with the necessary information, and an attractively presented product that represents excellent value for money. The product must be delivered with speed and a guarantee is offered by the distributor. Of great importance to the consumer is how to care for body, health and theh environment. Those factors result in the distribution becoming more and more important. In order to sell on the international market, excellent quality must be guaranteed as well as strict safety measures and commitment to the environment.

Up until a few years ago growers used to think that a good quality product was that meeting present-day demands for colour, flavour, size, weight, homogeneity. Currrently, three basic requirements have been added to this list to fulfil the customer's demands:

- Products with no chemical residues;
- Vegetables produced with no detrimental impact on the environment; and
- Vegetables produced with the health and safety of the growers in mind.

The main objective of UNE 155001 is to meet these three requirements, so using MB makes no sense anymore. This controlling certified system has some advantages for the whole society, such as:

For the producers, because a reduction in the inputs will mean a measure to encourage saving in exploitation and its management based on a better quality of growing by means of a superior professional training for growers.

For consumers, excellent quality guaranteed thanks to the reduction of the phytosanitary residues and the control of the whole production process.

For society, by contributing to the social welfare. Chemical inputs are reduced and the company is bound to control and try to get the disposal of solid waste in order not to adversely affect the environment.

The Committee of Normalisation is made up by those responsible for drawing up the norm UNE 155001 (all the organizations and institutions representing both producers and exporters in Almería). They are representatives of MAPA, the Ministry of Economy, Department of Health, Consumption and the self-governments in Andalucía, Canarias, Cataluña, Extremadura, Murcia and Valencia. Institutions representing the national and provincial production are FEPEX, CCAE and some agrarian organizations such as ASAJA, COAG, UPA as well as some associations of producers and exporters from the main exporting areas. Some others are also taking part of it, such as laboratories, EUREP and AENOR.

COEXPHAL has been advising the production companies and they have been requested not to use MB since 1997. UNE 155001 is in complete control of this situation and, in order not to make any mistakes, this norm is revised and checked once a month by an accredited institution, AENOR.

If in the course of any of its investigations it is discovered that a grower has used MB, the whole company will lose its certificate in compliance with UNE 155001. This will help to achieve compliance with the proposed goals, not only because growers feel duty-bound to goals but also because the growers truly believe this is the best thing to do.

ALTERNATIVES TO METHYL BROMIDE IN INTENSIVE HORTICULTURE IN ALMERÍA

According to the National Project, they are alternatives to the conventional use of the MB which are respectful of the environment, economical and viable. This project is being directed by MAPA within the framework of the national programme for development and research. Its results are really positive (Bolívar 1999).

The most used technique to disinfect grounds in intensive horticulture in this south-eastern part of the country is solarization (physical disinfection) or solarization combined with a chemical product (mixed disinfection). Solarization is a very effective method to disinfect the grounds in the greenhouses in Almería. Solarization effectiveness depends on the weather and the time of exposure. Almería the perfect for solarisation as soil temperatures in summer can reach 70ºC for 30 or 45 days. Solarisation is cost-effective and safe for people, animals and the environment. There are no chemical residues and it does not affect the physico-chemical properties of the ground. Yield increases after solarization probably due to pathogen control in the sandy soils.

Solarization combined with chemical products such as metam sodium in very small doses (100cc/m^2) appears to be better for controlling mobile organisms like nematodes that can move to deeper areas before later returning to the soil surface. Metam sodium is a nematicide, fungicide, herbicide and insecticide. Mixed disinfection is often used successfully in Almería. In addition to metam sodium, polyvalent phytomedicine fumigant for salty grounds has also proven successful. Where it is important to control mainly problems with nematodes, dicloropropene (1,3-D) is often used in drip irrigation together with the solarization with 80% success.

According to this growing system, the land is mostly made ("enarenado") of sand (90%) which is enriched with organic matter every two years. Nearly all varieties of organic matter can be used as a biofumigant, although its effectiveness depends on the dose and the way it is handled. Greenhouses in Almería have been making use of this technique – sand and dung, a wonderful biofumigant – for over 40 years, and it has always been preferred to MB.

Some greenhouses have had to try different methods to fight against some diseases such as *Fusarium* disease in watermelon. Growers found the solution to be grafted plants that consisted of a watermelon (sensitive to *Fusarium*) grown with a pumpkin root (resistant to *Fusarium*) (Bello *et al.* 1997, 1998). Grafted plants were safer for growers, less costly and more productive than MB.

CONCLUSIONS

Growers in Almería are responsible, dynamic professionals keen to learn new technological and agronomic improvements that could be included in their greenhouses. The successful adoption of alternatives to MB in Almeria, based on the efforts of growers in this region, could be considered as a model for growers in other regions of Spain.

It is interesting to note that nowadays, one of the most important things to be protected is the ozone layer. Eliminating MB would mean avoiding millions of cancer skin cancers and eye cataracts. Our environment has to be protected from anything dangerous or harmful.

We will do our best and we publicly declare our support to the proposal that MB be eliminated. We want to produce – and we do produce indeed, fresh vegetables guaranteeing the healthiness of the products as well as the respect for the environment. Thus, we think that all the alternatives that different researchers often give us should be carried out because they are proving to be really useful, depending on the growing system. The most important aspect seems to be spreading the information and training growers in how to use the alternatives.

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UNIDO PHASE – OUT PROGRAMME IN THE METHYL BROMIDE SECTOR

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INTRODUCTION

UNIDO as one of the implementing agencies under the Multilateral Fund has been engaged in the phase-out of methyl bromide (MB) in developing countries.

In the first phase, 22 demonstration projects have been implemented taking into account both climatic and social conditions in developing countries. More than 10 alternatives have been tested for their usefulness as both soil fumigants and for the treatment of commodities. The most suitable alternatives to MB have been selected by local farmers and other stakeholders in order to initiate phase-out programmes in more than 50 countries. Partial phase-out of MB has already taken place in certain developing countries thanks to the financial assistance provided by the Montreal Protocol's Multilateral fund.

In September 1997, Parties to the Montreal Protocol agreed a phase-out schedule for MB in developing countries, starting with a freeze in consumption in 2002. After a series of demonstration projects mainly conducted by UNIDO, the quick and enthusiastic response came from many developing countries requesting an earlier phase-out of MB. Indeed it is expected that in large and medium MB-consuming countries, a total phase-out (except essential uses) could be within reach in 2006, well in advance of the agreed phase out date of 2015 under the Montreal Protocol for developing countries. Advancement of the phase out date is mainly due to three major reasons:

- Alternatives are available and have proven effective in developing countries;
- Developing countries want to catch up with developed countries in terms of new technologies;
- Developing countries want to ensure continuity of exports to developed countries who may not accept products treated with MB after the deadline of 2005.

THE PHASE-OUT PROGRAMME OF UNIDO

UNIDO has implemented and completed 22 demonstration projects. The projects have involved various categories of alternatives (Table 1).

Table 1: Categories and types of alternatives to methyl bromide tested by UNIDO.

CATEGORY OF ALTERNATIVE	TYPE
Physical:	Solarization Steam pasteurization Floating trays Grafting Crop rotation
Chemical	Metam-sodium 1,3 D (telone) Phosphine Basamid Biofumigation
Biological alternatives	Biocontrol agents

ALTERNATIVES SELECTED AND LESSONS LEARNED

- Number of phase-out projects so far : 17
- Number of countries : 15
- Total ODP phase-out : 2,515 tonnes
- Total budget approved : US $ 24.8 million

PREPARATION OF NEW PROJECTS

- Number of phase-out projects in preparation for 2002: 10
- Number of countries: 10
- Total ODP phase-out expected: 500 ODP tones
- Total budget estimated: US$ 4.1 million

SPANISH NATIONAL PROJECT TO FIND ALTERNATIVES TO METHYL BROMIDE THE REMAINING CHALLENGES

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SUMMARY

The Spanish national project to find alternatives to methyl bromide (MB) was launched in 1997 with the short-term objective of finding alternatives to compensate for the reduction and ultimate cessation of the use of MB. Results achieved so far have overcome some of the fears expressed by the producers of strawberries and peppers under glass who are the main users of the product. Nonetheless, there are underlying problems which require further research in the near future targeted at ensuring the viability of these and other crops while also ensuring the utmost respect for the environment and sustainable agriculture.

Keywords: alternatives, ban, environment, viability, integrated production, methyl bromide

INTRODUCTION

Production areas in Spain

Andalusia, chiefly the province of Huelva, is Europe's main strawberry-producing region and one of the largest strawberry production areas in the world consisting of around 8,000 hectares and more than 1,800 producers. Strawberry growing has contributed to the economic and social development of various districts in the province of Huelva, transforming what were formerly depressed areas whose populations were forced to emigrate in search of better prospects into areas that now attract immigration.

On the other hand, the nursery subsector, with 46-48 producers of strawberry plants, is located chiefly in the Castile-Leon region, with some 1,000 hectares and more than 15.5 million mother plants.

In another area in Andalusia, on the north-western coast of the province of Cadiz, there is a large area producing horticultural crops and ornamental plants, particularly cut-flowers. These sectors are mainly family-run farms who use MB occasionally for production.

In the south-east of Spain, in the Campo de Cartagena region, is an area of approximately 1,300 hectares of greenhouses dedicated primarily to the production of thick-walled peppers for export. These producers comprise small and medium-sized family concerns as well as large company-run farms. In most of these greenhouses, the use of MB to disinfect soil is a standard technique.

In the Valencia region, with its extensive vegetable production and high level of citrus fruit production, MB has occasionally been used. In addition, a small area of almost 300 hectares is dedicated to strawberry growing. Cultivation methods, soil characteristics and climate in this region are significantly different to those in the province of Huelva, making it valuable to include it in the test network of the national project in order to compare results.

The brief description given above of some of the producing areas explains the anxiety and concern felt in the main producing sectors in 1995 that were dependent on the use of MB and were facing the prospect of the phasing out MB which the Vienna Conference (the Seventh Meeting of the Parties to the Montreal Protocol) had set as 1 January 2010. These fears were subsequently confirmed when the date for the definitive ban on MB was brought forward by the Parties to the Montreal Protocol to 1 January 2005 internationally for developed countries including the European Union. In these circumstances, at the beginning of 1997, the Ministry of Agriculture, Fisheries and Food and representatives of producers of strawberries and peppers under glass asked the National Institute of Food and Agricultural Research and Technology (INIA) to launch a research project to find viable alternatives to MB in the short term.

THE PROJECT

In March 1997, INIA brought together an eminent group of experts and gave them the task of drawing up a research project to find alternatives to MB in the short term which would be economically viable, environmentally-friendly and would maintain production volume and quality levels, in order to prevent economic and social progress being undermined for broad swathes of the agricultural population. The basic task was to launch a project combining research, testing and development, enabling the results obtained to be transferred directly to the producing sectors. It would have to be an essentially field-based operation involving the growers' own farms, in which the experimental plots would be designed large enough to apply the current techniques and equipment used by farmers. The project would also have to be dynamic in nature, so as to enable new hypotheses to be brought on board. These are distinctive characteristics distinguishing it from other ongoing research projects.

Researchers and their home research institutions responded enthusiastically to INIA's assignment, and this national project was developed and put into practice in four Autonomous Communities (Andalusia, Murcia, Valencia and Castile-Leon), with the participation of 10 research centres belonging to the Autonomous Communities of Andalusia, Murcia and Valencia, the Scientific Research Council (Consejo Superior de Investigaciones Científicas) and INIA, and the participation of academics from the universities of Almería, Huelva and the Universidad Politécnica de Valencia. I must also mention the valuable cooperation given by the associations Freshuelva, Asociación de Viveristas de Fresa, FECOAM (agricultural cooperative federation of Murcia), VALSUR de Valencia and the farmers who made their own farms or those of their partners, and their technical experts, available to the project.

The project studied various hypotheses, some based on chemical soil treatment, others on physical soil processing, or a combination of these. The project was designed to run for five years. As regards strawberry production, the fifth year of the project in 2002 has mainly been devoted to establishing demonstration fields to transfer to the production sector the MB alternatives which proved most viable in previous years. For the other crops, tests have continued as in previous years.

I must mention one factor - not, in this case, a scientific aspect - which was vital to the successful completion of the project and that is the funding provided, with exemplary coordination of efforts, by three Ministries: Agriculture, the Environment, and Science and Technology.

RESULTS

Over the last few days we have had the opportunity to hear the various members of the research team present the work they have carried out and the results they have obtained and so I shall summarise the results strictly in terms of cutting down on the use of MB and doing away with it completely in the near future.

Implementing some of the techniques tested has proved to be a trouble-free solution to achieving the successive cuts in levels of MB use laid down in Regulation EC2037/00 of the European Parliament and of the Council of 29 June 2000 for the cultivation of peppers under glass and strawberries. Some of the techniques tested suggest that discontinuing the use of MB should not cause serious immediate problems in these two crops, which have great economic and social impact in the areas where they are grown. Similar results are reported for other horticultural crops.

The techniques tested in strawberry plant nurseries and in cut flower production have not so far provided very good alternatives to MB. The following points should be made with regard to these two areas:

- It is essential that nursery plants are guaranteed optimum standards of health since they provide the basis for fruit production;
- Solutions such as the use of steam in cut-flower production may continue to be beyond the means of small producers because of the high costs involved and, what is more, the success of this technique depends to a great extent on the type of soil to which the steam is applied.

THE REMAINING CHALLENGES

Further research into alternatives must be undertaken for the last two cases mentioned, strawberry-plant nurseries and cut-flower production. Techniques for the application of the MB alternatives found for strawberry and pepper crops grown in greenhouses must be refined in order to minimise the impact on the environment.

There is also uncertainly as to how, over coming years, the fauna and flora of soils that have for decades been treated with MB will develop when MB finally ceases to be applied and is replaced by alternative methods. We must continue to monitor the situation closely. In particular, virulent strains of nematodes may develop which are hard to control with other nematocides.

Alternatives to MB must be found for problems such as soil fatigue, which is an acknowledged problem for tree crops but hardly ever accepted as existing with arable crops even though we have grounds to believe it does exist.

Debates on the future of agriculture focus on integrated production, an attempt to exploit natural resources to the full in order to sustain and protect crops while minimising the impact of agrochemicals. However, saying is one thing and doing another. Although there has certainly been a great deal of discussion about integrated production, there has been little research into making it socially viable. The competitiveness of integrated production is based on the higher prices that certain social groups, generally with a high level of purchasing power, are prepared to pay for its products, entailing clear discrimination against other, less well-off sectors.

While it is clear that we have to safeguard the environment for the benefit of future generations, it is no less clear that we face the problem of a growing world population, whose essential nutritional needs - and the equally essential need for reasonable standards of welfare - must be satisfied. This is one of the main challenges which research must tackle, for both aspects, supporting the human population and protecting the environment, are key to the concept of sustainable agriculture.

Logically, before turning to matters of production and contamination, there are controversial philosophical, and sometimes dogmatic, questions that arise if we do not consider the many aspects and social and economic implications of the matter. This is another area where multidisciplinary research, free of preconceptions, has a great deal to do in making a balanced assessment of the situation.

In conclusion, these are some of the remaining challenges posed not just by the ban on MB but by the need to ensure continued life on earth. Our work cannot be considered to be over. Instead, we must remain alert to any possibility which may arise which may feed into research, constantly bearing in mind the imperative to safeguard the environment and provide support to our neighbours throughout the world.

ALTERNATIVES TO METHYL BROMIDE TO CONTROL BLACK SHANK DISEASE (*PHYTOPHTHORA NICOTIANAE* BREDA DE HAAN) IN TOBACCO IN CUBA

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ABSTRACT

Cultural, biological, and physical alternatives were investigated as methyl bromide and some other fungicides such as metalaxyl were shown to be ineffective in preventing epidemics of Black Shank Disease (*Phytophthora nicotianae* Breda de Haan) in tobacco in Cuba. Soil solarization for 30 days, the use of *Glomus spp*, and the use of the *Trichoderma harzianum* according to *P. nicotianae* soil infection levels, were all highly effective in reducing *P. nicotianae* inoculum levels and disease incidence. Disease incidence was also reduced by selecting areas for the seedbeds free of this disease and by using crop rotation in the seedbed production areas.

Keywords: Black Shank Disease, tobacco, Cuba, solarization, seedbeds, methyl bromide, alternatives

FLOATING TRAY TECHNOLOGY WITH ORGANIC SUBSTRATE AND BIOLOGICAL CONTROL AS AN ALTERNATIVE TO METHYL BROMIDE IN CUBAN TOBACCO PRODUCTION

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ABSTRACT

Farmers have played the most important role in the adoption of new technology that will lead to the phase out of methyl bromide (MB) for tobacco seedling production in Cuba. Farmers were first made aware of the requirement to phase out MB, which was followed by an increase in extension services advice and preparation of teaching materials. Using group and individual teaching techniques, almost 790 farmers were trained in workshops and conferences, and by demonstrating alternatives in the field. Almost 900 visits to individual farmers were made by extension staff. More than 250 farmers have already adopted the floating tray technology which is evidence of widespread farmer interest and the success of the programme.

Keywords: tobacco, floating tray technology, methyl bromide, alternatives, Cuba

DIMETHYL DISULFIDE AS A NEW POTENTIAL ALTERNATIVE TO METHYL BROMIDE FOR SOIL DISINFESTATION

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ABSTRACT

The use of chemical compounds and especially fumigants remains a safe curative tool to control large populations of soil-borne pathogens, nematodes and weeds. A new fumigant produced by Atofina called dimethyl disulfide (DMDS) shows promise as an alternative to methyl bromide. Preliminary laboratory experimental results showed DMDS was biologically effective against several resistant forms of soil-borne fungi. At 20°C, the DMDS calculated Concentration Time Products (CTPs, in g.h/m^3) required for 90% efficacy were: 1981 g.h/m^3 for *Sclerotium rolfsii,* 3017 for *Rhizoctonia solani,* 3203 for Ph*ytophthora cactorum* and 3249 for *Sclerotinia sclerotiorum*. The physical and chemical behaviour of DMDS was also studied using small soil columns *in vitro*. In the short term, the goal is to understand the diffusion of DMDS in soil. The results show a good diffusion of this gas to a depth of 33 cm at 20°C in sandly loamy soils. A dose of 800 kg/ha of active ingredient is expected to result in lethal CTPs in the soil.

Keywords: dimethyl disulfide, alternative, methyl bromide, nematode, weeds, soil fumigant

CYANOGEN AND CARBONYL SULFIDE AS POTENTIAL QUARANTINE FUMIGANTS FOR TIMBER

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ABSTRACT

Carbonyl sulfide is a good fumigant for insect and nematode control and a substantial amount of work has been done on stored product pests using this fumigant. An application dose of 60 g/m^3 for 48 hour will control all life stages; and 80 g/m^3 controls or inhibits most grain fungi. Carbonyl sulfide penetrates and diffuses through both hard and soft timber more quickly than does methyl bromide (MB). The sorption is much less than MB so that effective internal concentrations may be attained. Desorption is very rapid; one day of airing post fumigation results in a headspace concentration less than the Australian experimental TLV of 10 ppm. Cyanogen is a potent biocide that controls insects, nematodes, fungi and bacteria. It also kills seeds and therefore is not suitable for many grain applications. No existing timber fumigant has a comparable range of biocidal activity. Cyanogen therefore has the potential to be effective against the full range of organisms that may be associated with timber in international trade. Cyanogen penetrates and diffuses through both hard and soft timber more quickly than does MB and also diffuses across the grain. Sorption on timber is similar to MB. Desorption is more rapid than other known fumigants.

Keywords: cyanogen, timber, fumigation, insects, nematodes, fungi, bacteria, biocide

BIOFUMIGATION WITH SOLARIZATION FOR SOIL DISINFECTION AND SUSTAINABLE PRODUCTION OF GREENHOUSE-GROWN SWEET PEPPER IN THE SOUTHEAST OF SPAIN

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ABSTRACT

In the Region of Murcia in South-East Spain, 1,433 ha of sweet pepper are grown in plastic greenhouses. *Phytophthora capsici* and *Meloidogyne incognita* are the main soilborne pathogens. Every year, soils are disinfected with methyl bromide (MB, 98%) with chloropicrin (2%) at 30 g/m^2, applied under a VIF (Virtually Impermeable Film) plastic mulch. Since 1998, biofumigation with solarization has been trialled as an alternative to MB in crops grown under an Integrated Pest Management (IPM) programme and those produced under an organic programme. The following aspects were studied in commercial and experimental greenhouses, and compared to MB and non-treated soil: i) biofumigation timing ii) which organic amendments to use and iii) the effects of reiterated biofumigations. The effect of disinfection on *P. capsici*, *M. incognita*, weeds, plant development, yield and the physico-chemical characteristics of the soil were measured. The best results were obtained when biofumigation with solarization was applied at the end of August or the beginning of September. Sweet pepper yield using fresh sheep manure with soy bean flour, or fresh sheep manure with chicken manure treatments, was similar to sweet pepper yield when MB was used. The reiteration of biofumigation with solarization over two or more years led to an improvement in pathogen and weed control, higher plants, an increase in yield and improvements to the soil physical properties, with a higher level of macro- and micronutrients as well as electrical conductivity.

Keywords: biofumigation, methyl bromide alternatives, sweet pepper, greenhouses, sustainable agriculture.

TECHNICAL AND ECONOMIC FEASIBILITY OF CHEMICAL AND PHYSICAL ALTERNATIVES TO METHYL BROMIDE IN SOIL DISINFESTATION OF TOMATO IN MOROCCO

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ABSTRACT

Solarisation, optimal use of fumigants, reduced dose methyl bromide (MB), steam pasteurization of soil and soilless cultivation, all within an Integrated Pest Management programme, were evaluated as alternatives to MB for control of severe root-knot nematode soil infestations. Soil solarisation using a transparent plastic mulch (45µ) increased soil temperatures to 48°C. Soil solarisation for six weeks alone, or four weeks in combination with metam sodium or 1,3-dichloropropene and soil pasteurization, gave similar control of root-knot nematode infestations as that obtained with a full or reduced dose of MB combined with VIF. An economic feasibility assessment of these alternatives supported these technical results. The project was part of an UNIDO project PROJECT/MP/MOR 97/126 funded by the Multilateral Fund of the Montreal Protocol.

Keywords: Solarisation, methyl bromide, steam pasteurization, root-knot nematode, metam sodium, 1,3-dichloropropene, Morocco

CHEMICAL AND NON-CHEMICAL CONTROLS USED IN URAGUAY AS ALTERNATIVES TO METHYL BROMIDE FOR NEMATODE CONTROL

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ABSTRACT

This two year project focused on demonstrating the effectiveness of several alternatives to the use of methyl bromide (MB) as a soil fumigant in protected horticulture. The use of metam sodium alone or combined with soil solarization gave good results in controlling nematodes and producing, in some cases, the highest yield in summer cycles. Bio-fumigation with corn or broccoli with soil solarization performed very well but, in the case of corn, the results were outstanding and could be compared statistically to MB. Generally, organic amendments increased populations of antagonist bacteria in the soil and improved its physical and chemical characteristics. This project was performed by INIA and UNIDO was the implementing Agency of the Multilateral Fund.

Keywords: methyl bromide, metam sodium, solarization, nematodes, corn, broccoli, organic amendments, Uruguay

BIOFUMIGANTS SUPPRESS FUNGAL PATHOGENS AND WEEDS OF STRAWBERRY

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ABSTRACT

This study examined the release of isothiocyanates (ITCs) from Brassica crops into soil. It demonstrated that the quantity and diversity of ITCs released into soil varied between Brassica species. Brassica roots released greater quantities of ITCs into soil than their shoots. The release of ITCs into soil peaked 4 hours after incorporation. These factors influenced the degree that biofumigants suppessed the growth of fungal pathogens and weeds of strawberry *in vitro*. In the field, biofumigation reduced weed growth by 30% and the growth of *Phytophthora cactorum* by 10%.

Keywords: isothiocyanates, brassica, biofumigants, methyl bromide, alternative, weed suppression, fungi

MICROFLORA AND NUTRIENT CHANGES AFTER FUMIGATION

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ABSTRACT

This study compared the selectivity of four soil fumigants against saprophytic soil microflora and their effect on soil nitrogen status over time. On soil without a history of fumigation, treatment with Vorlex + CP®, Basamid®, Telone C35® or Bromafume® led to drastic changes in the population dynamics of fungi, bacteria and actinomycetes. Basamid® and Vorlex + CP® displayed the greatest selectivity against fungi. The concentration of soil nitrogen was altered significantly by soil fumigation, but was not necessarily related to an increase in crop growth. Clearly, nitrogen is not the only factor involved in the increased growth response observed in plants grown in fumigated soil.

Keywords: Vorlex, Basamid, Telone-C35, Bromafume, fungi, bacteria, actinomycetes, growth response, methyl bromide, alternative

ECONOMIC VALUATION OF METHYL BROMIDE ALTERNATIVES IN SPANISH STRAWERRY CROPS

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ABSTRACT

Experimental trials carried out in strawberry plots in southwestern Spain around Huelva on different alternatives to methyl bromide for soil disinfection were economically analysed to determine their profit per hectare, profit per kg and profit per unit cost. The trials were carried out in 1997/98 within the scope of the INIA SC97-130 project. Both physical and chemical alternatives to MB were tested in 12 different treatments. Chloropicrin (40) seemed to be a good alternative to MB (40) when considering profit per hectare. Solarisation + metam sodium (50) appeared to also be interesting for profit per kg and profit per unit cost.

Keywords: methyl bromide, alternatives, chloropicrin, solarisation, metam sodium, economic evaluation, profit

CUBAN SKILLS USED IN THE ECOLOGICAL MANAGEMENT OF PLANT PARASITIC NEMATODES

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ABSTRACT

For more than twenty years in Cuba, economic control of plant parasitic nematodes has been achieved in a range of crops using non-chemical methods. Technicians and farmers use non-chemical methods as a part of a national programme to reduce chemical pesticides. Alternatives include quarantine regulations as well as cultural, physical and biological control methods. The crops with the most non-chemical alternatives are vegetables (urban agriculture included), tobacco, coffee, banana and potato. Sometimes an alternative consists of crop rotation with a crop that is not susceptible to nematodes such as peanut, sesame, corn, sorghum, sweet potato, garlic, and onion. Other methods include trap crops, soil tillage, elimination of weed hosts, use of non-decayed organic matter, clean seedlings, selection of sites as free as possible of pests and disease, and biological control with fungi and bacteria. Integrated Nematode Management Systems have been developed for different crops such as coffee, banana, vegetables and potato.

Keywords: Cuba, non-chemical, nematode, crop rotation, trap crop, soil tillage, biological control

EFFECT OF SOIL SOLARIZATION ON THE VIABILITY OF *FUSARIUM OXYSPORUM* F. SP. *DIANTHI*

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ABSTRACT

A comparison was made of the differences between the ability of three different types of plastic sheet to solarize soil in a closed greenhouse in southwest Cádiz from late June to early August 2001. Soil temperatures were recorded over time in each of the different treatments. Sequential sampling of soil samples naturally infested with *Fusarium oxysporum* f.sp. *dianthi* buried at two depths indicated that full control of the fungal pathogen was achieved at 15 cm depth after 30 days solarization in all treatments. Pathogen viability loss was 100% at 30 cm depth after 30 days when PE CP-129 40µm was used, after 37 days using the yellow plastic 180µm treatment, and ca. 6% after 44 days of solarization with polythene 50µm.

Keywords: solarization, plastic sheet, fungal pathogens, *Fusarium oxysporum*

ALTERNATIVES IDENTIFIED FOR VEGETABLES IN UNEP'S REGIONAL DEMONSTRATION PROJECT ON METHYL BROMIDE ALTERNATIVES IN CENTRAL AND EASTERN EUROPE

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ABSTRACT

A two year evaluation of chemical (dazomet, 1,3-D+CP) and non-chemical (*Trichoderma viride,* Indian mustard or straw amendments) alternatives was conducted in field-grown cabbage, tomato and celeriac. The yield increases of cabbage and tomato following application of dazomet and 1,3-D+CP integrated with *Trichoderma* were lower than the yield when methyl bromide (MB) was used, but still the yields were commercially acceptable. Celeriac showed a stonger response to alternative treatments. Dazomet and 1,3-D+CP integrated with *Trichoderma* significantly increased the marketable yields of celeriac. The combined applications of lower rates of 1,3-D+CP or dazomet with the biocontrol agent was superior to those chemicals used alone at higher rates. The results indicate that in the production of celeriac both dazomet alone and 1,3-D+CP at a lower dosage combined with *Trichoderma* can be considered as one-to-one replacements for MB.

Keywords: dazomet, 1,3-dichloropropene, cabbage, tomato, celeriac, Poland, alternative, methyl bromide

IODOMETHANE (TM-425) - DEVELOPMENT AND REGULATORY UPDATE

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ABSTRACT

TM-425, (active ingredient: Iodomethane) is in commercial development as a replacement for current uses of methyl bromide (MB). TM-425 is an environmentally friendly, broad-spectrum fumigant applied to soil for the control of various economically important weed seeds, plant parasitic nematodes and soil borne pathogens. Target markets include strawberries (including nursery production), fresh market tomatoes, turf and ornamentals (cut flower and bulbs). Research has demonstrated there are no detectable residues in all fruits tested (less than 0.01 ppm) and its half-life in soil and air is short (less than 5 days). TM-425 has an extremely low ozone depletion potential (ODP). TM-425 is a superior quality material, which can be used as a drop-in replacement for MB. The spectrum of activity of TM-425 and its TM-442 combinations is equal to or superior to commercial standards. Additionally, there is strong evidence of increased yields resulting from treatment of fresh market strawberry and tomato fields.

Keywords: Iodomethane, TM-425, alternative, methyl bromide, tomatoes, turf, ornamentals, strawberry, tomato

INTRODUCTION

Arvesta Corporation, formerly Tomen Agro, Inc., is a multinational company having as its core business agricultural products. Arvesta focuses on premium - branded products and is active in worldwide development, registration, manufacturing and sales. Chloropicrin (TM-442), one of our proposed mix partners, is included in our manufacturing portfolio of products.

TM-425, (active ingredient: Iodomethane) is in commercial development as a replacement for current uses of methyl bromide (MB). TM-425 is an environmentally friendly, broad-spectrum fumigant applied to soil for the control of various economically important weed seeds, plant parasitic nematodes and soil borne pathogens. Target markets include strawberries (including nursery production), fresh market tomatoes, turf and ornamentals (cut flower and bulbs). Pre-plant fumigation to soil is shank applied by conventional equipment typically used for flat / broadcast, prepared raised bed or through buried drip line fumigation.

RESULTS

Field efficacy trials conducted in the United States support rates of 134 – 263 kg/Ha for TM-425. Testing has been conducted with TM-425 and in combination with chloropicrin (TM-442). Formulations in development include TM-425: TM-442 ratios of 98:2, 50:50 and 25:75. Additional formulations are under evaluation. Rates are dependent upon target species, soil conditions, texture, and cultural practices. TM-425 formulations are well suited for both field and glasshouse applications.

In 1999,Tomen Agro placed TM-425 in a Biological Development program as a soil fumigant and replacement candidate for methyl bromide. Regulatory briefings with regulatory agencies the in U.S., EU and Japan have been held. Conferences with the U.S. EPA and California Department of Pesticide Regulations have been favorable resulting in TM-425 being given an EPA top priority and the expectation of an accelerated review process. Target data package submissions and registration/sales are the following:

January 2002 United States submission; January 2003 United States registration; February 2003 Israel submission; March 2003 Israel registration; March 2005 EU and Japan Submissions; March 2006 EU Provisional Sales; December 2006 Japan Sales.

Compared to MB, there are a number of advantages when TM-425 is used. Research has demonstrated there are no detectable residues in all fruits tested (less than 0.01 ppm) and its half-life in soil and air is short (less than 5 days). TM-425 has an extremely low ozone depletion potential (ODP). The calculated ODP value is 0.0015, which US EPA confirms, makes it a non-threat to the ozone layer. Importantly, TM-425 is a liquid at ambient temperature and can be handled and stored using conventional equipment. Research confirms it is well suited for use in closed systems for pre-plant soil fumigation including buried drip line irrigation. The end result is reduced potential for worker exposure.

Data from various field trials have shown increased yields in crates/ha for strawberries. TM-425 at196 kg/ha, and TM-425 + Chloropicrin at 270 (50:50 ratio) and 331 kg/Ha (60:40 ratio) were equivalent or superior to the commercial standard, MB + chloropicrin @ 393 (263 +130) kg/ha (Table 1). Data from tomato field trials show increased yields of marketable fruit as much as 123% of yields harvested for MB (Table 2).

Efficacy results for TM-425 reflect a spectrum of activity similar to what is observed with MB-treated soil. However, TM-425 is effective at rates lower than standard MB rates. This increased effectiveness is mostly attributed to retention of a higher concentration over time in the soil. Because TM-425 is a liquid as it is injected into the soil it will penetrate further in the soil profile before it enters a gas phase. TM-425 vapor pressure and Henry's Law constant still classify this chemical as a true fumigant, which means that it will move as a gas in all directions through the soil profile.

CONCLUSIONS

TM-425 is a superior quality material, which can be used as a drop-in replacement for MB. The spectrum of activity of TM-425 and its TM-442 combinations is equal to or superior to commercial standards. Additionally, we have strong evidence of increased yields resulting from treatment of fresh market strawberry and tomato fields.

Table 1: Effect of fruit yields as a percent of yield from methyl bromide treated soil. Methyl bromide applied at 393 kg/Ha, 67:33 ratio. Average from two strawberry field trials in California.

Treatment	Rate	Ratio	Percent Yield
TM-425	196 kg/Ha	Stand alone	103%
TM-425 + TM-442	270 kg/Ha	50:50	93%
TM-425 + TM-442	331 kg/Ha	60:40	100%

Table 2: Effect of fruit yields as a percent of yield from methyl bromide treated soil. Methyl bromide applied at 393 kg/Ha, 67:33 ratio. Average from a single tomato field trial in Florida.

Treatment	Rate	Ratio	Percent Yield
TM-425	196 kg/Ha	Stand alone	94%
TM-425	263 kg/Ha	Stand alone	123%
TM-425 + TM-442	268 kg/Ha	50:50	120%
TM-425 + TM-442	331 kg/Ha	60:40	135%

AGROCELHONE, THE SOLUTION AGAINST NEMATODES AND SOIL FUNGI AS AN ALTERNATIVE TO METHYL BROMIDE

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ABSTRACT

The poster consists of number of studies performed with *AGROCELHONE N* and *AGROCELHONE NE* as alternatives to methyl bromide. These studies have been done in strawberry, tobacco and vegetable crops in Andalucia and Extremadura areas during the years 1998, 1999, 2000 and 2002. In the poster, the rates used, the application methods employed, the assessments, results and conclusions are described for each crop in turn. Trial photographs, graphs and results are included to assist in interpretation of the poster.

Keywords: Agrocelhone, dichloropropene, chloropicrin, methyl bromide, product, nematodes, fungus, efficacy trials, tobacco, strawberry, vegetables.

STRAWBERRY

Methods and application

During the seasons 98/99 and 99/00, nematicides and fungicide efficacy trials were performed on strawberry in the Huelva area with the product **AGROCELHONE N**: *Dichloropropene 59.6% p/p + Chloropicrin 34.6% p/p.* Trials were also carried out with **AGROCELHONE F** formulated with different 1,3-D and chloropicrin rates. The experimental design was randomized blocks with 3 thesis and 4 replicates.

The following test were run:

AGROCELHONE N

THESIS	PRODUCT	DOSES/Ha
1	AGROCELHONE N	180 Kg[1]
2	67% Br + 33% Cl	400 Kg
3	UTC	Plastic

[1] In some trials 500 Kg/Ha rate was applied

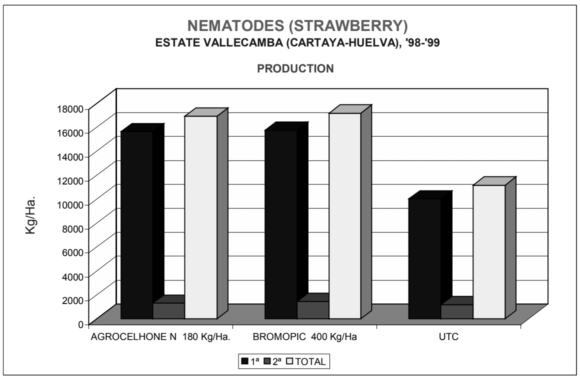
The applications were done in two passes through an injection mechanism located in the soil during the season 98/99. The plots were stamped with waterproof plastic, and it was taken away after 5 days. The treatment was performed in bands and in two passes: Alternative bands were treated in the first pass and untreated bands in the second pass. The machine used in the treatment was an specific applier for located injections to the soil. The application method used in the season '99/'00 was an injection mechanism located at soil in the plantation back. The back was stamped with waterproof plastic with the purpose of getting it ready for the transplant of the crop.

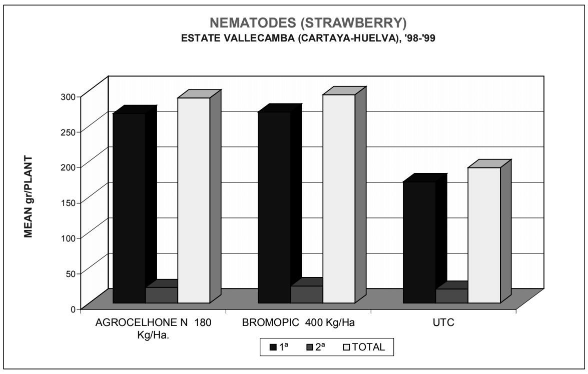
Assessments

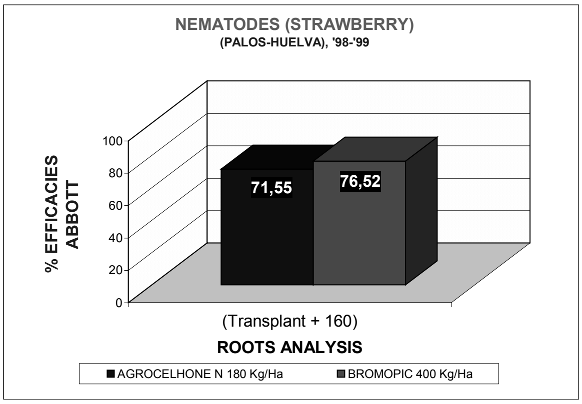
The sampling were performed on plants, seeing the air symptoms, on roots nodule index (on roots affectation index in fungus trials), on vegetative development, taking 10 randomized plants/elemental plot. The flowers/plant number and fruits/plant number were reported, taking 10 randomized plants per elemental plot. An estimation of production was done per treatment, weighing 20 fruits per repetition taken at random (all harvestable fruits of first and second quality). Moreover a sample composed of neck and roots of affected plants was taken and it was carried to the laboratory for its analysis.

CONCLUSIONS

The **AGROCELHONE N** product proves to be in most cases, good disinfectant of soil against nematodes and soil fungus. This product can be compared with the MB, reaching similar results on efficacy, vegetative development, fruit number/plant, mean weigh/fruit and production that the plots disinfected with *67% Br + 33% Cl* and better of course than untreated plots.







TOBACCO

AGROCELHONE N: *Dichloropropene 59.6% p/p + Chloropicrin 34.6% p/p*

METHODS AND APPLICATION

On 1999 three trials were performed against nematodes on tobacco crop in Talayuela (Cáceres). The experimental design of each trial was randomized blocks with 3 thesis and 4 replicates.

The application method used was through injection mechanism located at flat soil on all the land. The land was stamped with soil through an iron platform fitted to the application machine. The machine used was an specific applier for the located injections at the soil.

On 2000 two assays against nematodes in Talayuela (Cáceres), comparing **AGROCELHONE N** at 150 Kg/Ha with 1-3 D at 120 Kg/Ha. The trial had two replicates in two plots with different textures (sandy and clearly-sandy). The application method used was through injection mechanism located at flat soil on all the land. A machine was used with 3 parts.

The following test were run:

THESIS	PRODUCT	DOSES/Ha
1	1,3-D INJECTABLE	150 l
2	AGROCELHONE N	180 Kg
3	UTC	

Assessments

The assessments done in these trials in 1999 are performed through roots analysis in the laboratory in transplant and after it, with the purpose of to see the nodule index.

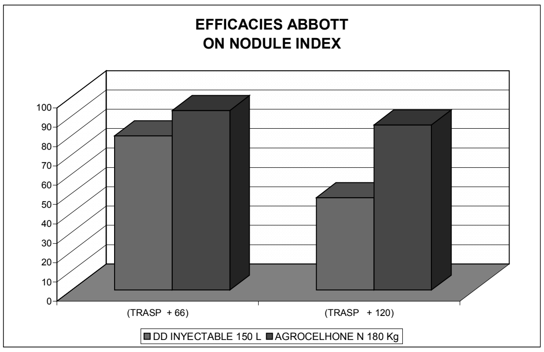
Two assessments on vegetative development are also done to see if some difference exists between treatments and control, taking 10 plants/elemental plot before flower removal, reporting the height in cm, the length and leaves wide.

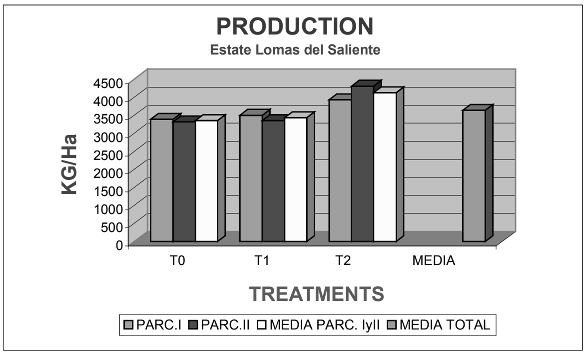
In the trials performed on 2000, the crop data were reported, such as transplant, ploughing, flower removal, phytosanitary treatments, growth rate, colouration, shoots development, pests, illness and ripeness.

- One hundred plants per elemental plot are harvested.
- Yield in Kg/Ha of tanned tobacco per foliar flat and elemental plot.
- Physical assessment of tanned tobacco per foliar flat and elemental plot.
- Chemical assessments of tanned tobacco per foliar flat and elemental plot, reporting about total alcaloides, reducer sugares, relation reducer sugar/total alcaloides and chloruros.
- The nematode attack in roots was evaluated in order to scale 0 to 10 after the last harvesting.
- A sample per foliar flat and elemental plot was taken composed by 48 samples (2 trials, 2 repetitions, 3 thesis and 4 foliar flats).

CONCLUSIONS

AGROCELHONE N proves to be a good soil disinfectant against nematodes, with high populations of *Meloidogyne* spp., in all the trials done. The product obtains better efficacies than 1,3-D INJECTABLE product, obtaining at the same time better development of the plant and higher yielding.





(*) T0 (UTC) T1 (1,3 D INJECTABLE) T2 (AGROCELHONE N)

VEGETABLES

AGROCELHONE NE: *Dichloropropene 59.6% p/p + Chloropicrin 34.6% p/p*

During last years, it has been performed trials with this product in greenhouses in several vegetable production areas (tomato and pepper crops fundamentally) in Almería and Murcia areas. It has been reached high efficacy indexs, comparable with the MB product and better than those of others disinfectants compared also (1,3-D and metam-sodium), applied through located irrigation prior to transplant of the crop on all the land and stamping the soil with a plastic. The plastic is keeping during 10-12 days after application

Nowadays, some trials with this product are being performed, in greenhouses in Los Palacios (Sevilla) area. This product is being applied through located irrigation before crop transplant, on all the land and stamped with a plastic. It must pass 28 days before transplant. The rate is 400-500 Kg/Ha. Before application it is irrigated with the purpose of get the very best humidity (60%-70%). It is applied at 2 g/l, equivalent to 2.000 ppm, and it is irrigated about 3-5 l/m^2 after application with the purpose of clean the pipelines and stamp the product in the soil.

Nowadays other assays are being performed in other vegetables with this product with the same rate and application method. The assessments are done on nodule index of nematodes and on infestation of neck and roots fungus and, in some cases, on production.

ALTERNATIVES TO THE USE OF METHYL BROMIDE IN BANANA PRODUCTION IN COLOMBIA

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ABSTRACT

In order to show the world's banana industry that there are technically and economically feasible alternatives to methyl bromide (MB) in an integrated Moko disease management programme, the fumigant Dazomet (Basamid ®) and the herbicide Glifosato (Roundup ®) were evaluated alone and in combinations, in the two main Colombian banana growing zones (Urabá and Magdalena). Results of the first replication show that the four treatments used to eradicate banana plants infected with the bacterium *Ralstonia solanacearum* (causal agent of Moko), were effective and none of the replants in post-treated plots showed symptoms of the disease from planting to flowering. The second replication showed over 90% of plants infected, 15 and 30 days after the inoculation in Urabá and Magdalena, respectively, being the disease evolution faster in the first zone. Lab analysis, on post-treatment vegetal tissue samples from all treatments, detected the presence of bacteria colonies with a similar morphology to that of the causal agent of Moko. However, no symptoms of the disease were found on greenhouse plants after the inoculation with inoculum prepared with these bacteria.

Keywords: methyl bromide, alternatives, banana, Colombia, Moko disease, dazomet

INTRODUCTION

In Colombia, there are records of methyl bromide (MB) utilization in the banana growing zone of Urabá - Atioquia up to 1993 and in the Magdalena Province there are records of its utilization up to 1995. Basically, MB was used in banana crops to control Moko disease or "maduraviche" caused by the bacterium *Ralstonia solanacearum* (Mejía 1995 & Granada 1997).

Joint efforts of producers and different institutions enabled the development of alternative methodologies and strategies for the efficient handling of diseases, without MB. In the case of Moko disease, Augura implemented the phytosanitary brigades strategy to diagnose and control the disease through the herbicidal eradication of infected plants in the Urabá and Magdalena regions, the main two areas under export-quality Cavendis*h* banana (*Musa AAA*) cultivation (Quiros 1984 & Rosero 1985). The objectives were to watch over the phytosanitary maintenance of the zones, the periodical revision of infected and neighboring farms, the prevention and control of diseases found in the area, statistical data-gathering in relation to diseases and sharing of information with other entities. These activities allowed a notable reduction in the incidence of the disease, and the proposal of new projects and research topics during the program (Mejia 1996 & Mena 1999).

This study attempts to demonstrate that there are alternatives to MB in the control of Moko disease. For this purpose, four treatments, with 2-replications, for the control of Moko disease in the two main banana growing regions (Urabá and Magdalena) in Colombia were evaluated (MB, Dazomet, Glifosato and the combination Glifosato + Dazomet). The treatments were evaluated from the economic and efficacy point of view.

MATERIALS AND METHODS

The demonstration was conducted in two 0.5-hectare Plots. One is located in Uraba, Municipality of Carepa, Antioquia Province, Colombia. The other one is located in Zona Bananera Municipality, Magdalena Province, Colombia.

To improve soil porosity, the preparation of each plot was based on the analysis of its physical properties and included weeding, sub soiling and two harrow passes. Each area was subdivided into 4 plots of 0.1 hectare each. Each experimental lot was planted with 720 plants from meristems of Great Dwarf Cavendish banana in 30 X 30 X 30 cm holes, at 2.5 m between plants and 2.5 m between rows. Each plot included 180 plants, occupying a net area of 962.5 m^2, a total net area of 3.850 m^2 for each zone.

To work with the specific bacterium, the inoculum was prepared directly from fresh diseased tissue obtained from the participating banana growing regions, to preserve the bacterium's in-situ virulence, facilitate its preparation and to avoid possible alterations to the study and the environment. For the Uraba banana growing region, the inoculum was obtained from a 1-kg Great Dwarf Cavendish banana corm infected with Moko disease, located in lot 6 of the Dioselina farm, Carepa municipality, Antioquia Province, Colombia. For the Magdalena region, the inoculum was obtained from an infected corm located in parcel 1 of the Futuro Porvenir farm, Zona Bananera municipality, Magdalena Province- Colombia.

Each corm was soaked in a 10 % sodium hypochlorite solution for 15 minutes, then placed in an isolation chamber as aseptic as possible, and washed with sterilized water. A 300 g sample was taken from the so called "medal" (characteristic internal symptom of the disease) and liquefied with 2.7 liters of sterilized water. The suspension was then filtered and the motility and amount of bacteria was microscopically determined in Colony Forming Units CFU in 100 μl present in these solutions, pouring 100 microliters of each inoculum in a TZC culture medium. Five replications were performed. A few hours after inoculum collection and preparation, 2.5 cm^3 of the bacterial suspension was injected in the central part of the pseudostem of each plant.

Four treatments for the control of Moko disease were evaluated in each region, as follows: Plot 1, with 50 g/m^2 of MB commercial product, covering the entire plot with plastic during 8 days, including the infected plants. Plot 2, with 10 cm^3/plant of Glifosato (Roundup®) 20% commercial product in distilled sterilized water, applying 25 g/m^2 of Dazomet (Basamid®), 8 days later, covering the ground with plastic for 8 days. Plot 3, with 10 cm^3/plant of Glifosato (Roundup®) 20% commercial product in distilled sterilized water and were maintained in quarantine for six month. Plot 4, with 25 g/m^2 of Dazomet (Basamid®) incorporating the product into the soil and covering the entire plot, including diseased plants, with plastic for 8 days.

From each 180-plant plot where fumigants were applied, 30 samples of Moko diseased pseudostems were selected immediately after the tents were removed and taken to the lab, in order to detect whether bacteria were present in the treated samples. To corroborate its pathogenicity, the colonies obtained *in vitro,* from tissues after treatment, were evaluated in greenhouse and the Great Dwarf banana seedlings were inoculated (2 ml/plant at $1x10^3$ UFC concentration in a PCG liquid medium). All treated plots were planted with 180 Great Dwarf banana. These plants had been under six-month constant monitoring for Moko symptoms, from planting to flowering, in order to verify product efficacy in soil and a possible relapse of the disease. When each plot showed over 80% flowering, the plants, and all vegetal material generated within the plots, were removed and buried outside the plot to prevent neighboring producers from using them as seedlings. To obtain the necessary information for an economic analysis, the number of day's wages (men-day) needed in each one of the treatments were determined.

RESULTS AND DISCUSSION

The inoculum showed an average concentration of 22 and 21 Colony Forming Units (CFU), for Urabá and Magdalena respectively. 95% of the inoculated plants in Urabá showed Moko disease symptoms, in a period of 16 days after the inoculation. This zone shows a fast evolution of the disease. 50% of the plants showed symptoms of the disease just 10 days after inoculation (Table 1). In the Magdalena region, over 90% of the plants showed symptoms of the disease 30 days after the inoculation and 100 % infestation 35 days after inoculation. This zone showed a 15-day latent stage, then, the disease developed rapidly (Table 1). As in the first year, the Urabá region showed a faster development of the disease compared with the Magdalena region. This seemed to be related to the rainfall which is heavier in the Urabá zone.

In Urabá, total day's wages needed in each treatment, in descendent order, were: first year dazomet 18.36, dazomet + glifosato 16.62, MB 7.68, glifosato 0.39; and in the second year dazomet 13.14; dazomet + glifosato 9.58 and MB 5.29; (Table 2). In the Magdalena region, in descendent order, day's wages needed in each treatment were: first year dazomet + glifosato

8.48, dazomet 8.21, MB 4.96, glifosato 0.44 and in the second year, dazomet + glifosato 8.58, dazomet 7.3, MB 4.9 and Glifosato 0.44 (Table 3). Treatments to the soil, dazomet and glifosato + dazomet, demanded more labor compared with MB which does not require incorporation into the soil. In the case of Uraba, compared with the previous semester, all treatments demanded less labor, explained by a more worked soil and lower rainfall. However, the Uraba plot still demanded more labor compared with the Magdalena region, which has a more sandy soil.

Efficacy in tissue, the number of pseudostems that resulted positive for Moko disease, per treatment, were: in the second year Urabá; MB 28, dazomet 3 and glifosato + dazomet 16. However, in inoculated greenhouse plants, no symptoms of the disease were observed. Magdalena; MB 21, dazomet 16, Glifosato + dazomet 6. None of the inoculated greenhouse plants showed symptoms of the disease. These results suggest that isolated bacteria are not pathogenic after treatment, although it could be due to an after-treatment same genus bacterial colonization during the vegetal tissue decaying process, presenting the same type of colony (see Table 4). This may occur because the TZC culture medium is not specific for Ralstonia solanacearum and other species may grow in it.

Table 1: Percentage of Great Dwarf banana plants infected with Moko disease, in Uraba Antioquia and Zona Bananera, Magdalena - Colombia.

Time (days)	Uraba		Magdalena	
	Year 1	Year 2	Year 1	Year 2
5	0	0	0	0
10	80	51	1	4
15	88	89	10	12
20	96	99	83	66
25	97		98	80
30	100		100	94

Table 2: Day's wages per 0.1 hectare required per treatment for the control of Moko disease. Uraba –Colombia.

Labor	Methyl bromide		Dazomet + glifosato		Glifosato		Dazomet	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Soil movement	-	-	6.48	4.25	-	-	6.00	6.60
Product application	1.00	0.16	0.47	0.11	0.14	0.12	0.38	0.12
Plant removal and chopping	0.20	0.10	0.21	0.10	-	-	0.20	0.09
Product incorporation	0.00	-	2.00	1.26	-	-	2.10	1.50
Plastic installation	4.75	4.00	5.63	2.83	-	-	7.80	3.80
Pathways disinfections	0.13	0.03	0.13	0.03	-	-	0.13	0.03
Plastic removal	1.60	1.00	1.70	1.00	-	-	1.75	1.00
Weed Control	-	-	-	-	0.25	0.30	-	-
Total	7.68	5.29	16.62	9.58	0.39	0.42	18.36	13.14

Table 3. Day's wages per 0.1 hectare required per treatment to control Moko disease. Zona Bananera, Magdalena - Colombia.

Labor	Methyl bromide		Dazomet + glifosato		Glifosato		Dazomet	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Soil movement	-	-	3.00	3.50	-	-	3.44	3.00

Labor	Methyl bromide		Dazomet + glifosato		Glifosato		Dazomet	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Product application	0.13	0.13	0.35	1.25	0.15	0.13	0.22	0.90
Plant removal and chopping	0.16	0.15	0.19	0.14	-	-	0.21	0.16
Product incorporation	-	-	1.10	0.61	-	-	1.15	0.50
Plastic installation	3.90	2.50	3.00	2.30	-	-	2.30	2.08
Pathways disinfections	0.14	0.04	0.14	0.07	-	-	0.14	0.06
Plastic removal	0.63	0.66	0.70	0.71	-	-	0.75	0.60
Weed Control	-	-	-	-	0.29	0.32	-	-
Total	4.96	3.48	8.48	8.58	0.44	0.45	8.21	7.30

Table 4. Isolation of Moko-causing bacteria from treated banana tissue in TZC culture medium, and re-inoculation of positive colonies in greenhouse seedlings.

TREATMENT	Uraba				Magdalena			
	Laboratory		Greenhouse		Laboratory		Greenhouse	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Methyl Bromide	1	28	-	-	1	28	-	-
Dazomet	1	3	-	-	-	3	-	-
Gifosato + Dazomet	-	16	-	-	8	16	-	-

FIELD EFFICACY

All plants planted after the treatments were monitored for Moko disease symptoms from planting to flowering. None of the plants showed symptoms of the disease. This suggests that any of these treatments is effective to control de disease in the seedling stage. To decide for any of these treatments, it is then necessary to consider the economic and environmental aspects of each one of the treatments.

Economic analysis for both zones for the first year of the project, total costs of each one of the alternative methods compared to MB. Detail cost of treatment, cost of quarantine maintenance and loss of profits or earnings (during the time between disease treatment and the starting of production). Loss of profits or earnings was calculated multiplying time in weeks without producing by the average profits obtained from a hectare in production in the same period. Comparing MB to the herbicide Glifosato, the difference in costs for each heading is as follows: treatment 95% and 96 %, quarantine maintenance –64% and –90%, loss of profits or earnings –58% and –58 %, for Urabá and Magdalena, respectively. That's to say, Glifosato costs are 95% lower in Urabá and 96% lower in the Magdalena region concerning the heading "Treatment", and they are also 64% higher in Urabá and 90% higher in Magdalena concerning the heading "Quarantine Maintenance", and so on (dates not showed).

In the MB method, the weight of each heading is as follows: Treatment 81% and 79%, quarantine maintenance 2% and 2%, loss of profits or earnings 16% and 19%, for Urabá and Magdalena, respectively. In the Glifosato method, the weight of each heading is as follows: Treatment 12% and 9.2%, Quarantine maintenance 11.5% and 10.2%, and loss of profits or earnings 76.5% and 80.6%, for Urabá and Magdalena respectively. The heading with more weight in the MB method is "Treatment", while in the Glifosato method is "Loss of profits or earnings". What is more attractive is that the Glifosato method has a cost comparative advantage of 62% in Urabá and 58% in Magdalena, in relation to MB despite Glifosato's six month quarantine. This situation invalidates the belief that lower quarantine time means more profits.

The difference in costs between the two zones, is due to less labor required in the Magdalena region to perform the treatments. Total day's wages used in the Magdalena region were lower because of its sandy soil, which requires less labor than Urabá's clayish soil.

The cost of product, plastic and labor of MB and Dazomet treatments is a disadvantage from the economic point of view compared to the herbicide Glifosato, despite the relative high loss of profits caused by Moko disease control with Glifosato. The economic analysis shows that losses caused by Moko disease treated with MB and Dazomet are three times higher than the ones caused by the disease treated with Glifosato.

It is important to note that in a commercial banana plantation, where banana plants are in different development stages (flowering, fructification, etc.), the cost of handling the disease will increase because of the harvest and stacking of vegetal and plastic material present in the treated area. Besides, in these plantations, the disease will affect all type of plants (mother, daughter, granddaughter plants), which reduces fumigants' efficacy due to the greater amount of diseased biomass that must be treated. This will not happen when the Glifosato method is used for the control of Moko disease.

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FOUR YEARS RESEARCH ON IMPROVED SOIL SOLARIZATION AND OTHER ALTERNATIVES TO METHYL BROMIDE ON STRAWBERRY CROPS

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ABSTRACT

To develop alternatives to MB, it is necessary to study not only the efficacy of the treatments but also their long-term effects and the feasibility of repeating the treatment in the same field several years consecutively. A four year experiment was carried out in a strawberry field in which there were established seven treatments: non treated control; standard dosage application of MB (60g/m^2); half dosage application of MB (30g/m^2) using VIF tarp; moderate rates of manure (5kg/m^2) combined with solarization; reduced dosages of metam-sodium (MS) (35g/m^2) combined with solarization; MS at standard dosages (144g/m^2); and fresh manure at high rates (15kg/m^2). The solarization treatments were split in two sub-treatments in the last year, in such a way that a half of the solarization combined with manure treatment of the third year was replaced by solarization combined with MS and *vice versa*, so that the experiment had a total of 9 treatments. After four years of research, we can infer that improved solarization with manure offers the better possible alternative when data of the first two years are considered but there is a loss of efficacy if these treatments are uninterruptedly applied longer than two years. The replacement of MS for manure produced less marketable yield losses than the reverse replacement.

Keywords: methyl bromide, alternatives, solarization, metam-sodium, strawberry

INTRODUCTION

The strawberry industry is very important in Spain, ranking second in the world in strawberry production for fresh consumption right after the United States. Most of the land cultivated in strawberries is disinfested before planting using MB as a standard cultural technique to avoid disease incidence.

The MB consumption in Spain has been reduced by 50% since 1998, and it will continue declining up to the phase out in January 2005, according to the schedule approved by the EU. This means that there is an urgent need to find possible chemical and non-chemical alternatives to MB before that deadline.

As a consequence of the progressive importance that organic strawberry fruit production is acquiring in the European market, this cultural production system has to be included among the present and future studies; therefore, solarization by itself or even combined with fresh manure (Gamliel & Stapleton 1997) to increase the toxic effect of volatile compounds to control soil-borne pathogens, have to be taken under consideration. Furthermore, the fact that the soils of Valencia area are loam or clay ones with low drainage and they have a low organic mater content, offers an additional reason to examine the possibilities of these organic techniques as alternatives to MB. Also the possibility of reducing dosage of MB while keeping effectiveness was studied in our area by combining with solarization or using a VIF sheet (Cebolla *et al.* 1996) with a subsequent reduction of emissions to the atmosphere.

Chemical alternatives to MB, that are not harmful to the ozone layer, have been suggested by using fumigants such as MS at standard dosages or at low ones combined with solarization. Therefore, they have to be considered in this type of studies equally.

MATERIALS AND METHODS

The aim of this experiment was to compare the behaviour of treatments reducing MB dosage by using VIF tarp (3); fresh manure at large rates (15 kg/m^2) (7) and moderate rates (5 kg/m^2) combined with solarization (4); metam-sodium (MS) at standard dosages (140 g/m^2) (6) or reduced dosages (35g/m^2) combined with solarization (5). Non treated control (1) and standard dosage application of MB (60g/m^2) (2) were used as references. Tarping period for MB treatments was 5 days while the solarization treatments was 5 weeks. Manure composition was 75% fresh sheep and 25% poultry for the solarization improved treatment (4) and for the manure treatment itself (7).

The ranges of the main characteristics of fresh sheep manure for treatments 4, 5’ & 7 were 51.7 –52.3 for % dry matter; 58.5-67.9 for % total Organic Matter; 1.85-2.08 for % Total Nitrogen and 17.2-18.7 for C/N ratio; and for poultry manure the ranges were 54.2-81.2 for % dry matter; 51.3-70.3 for % total Organic Matter; 2.95-7.29 for % Total Nitrogen and 6.6-13.8 for C/N ratio.

The solarization treatments were split in two sub-treatments in the fourth year, in such a way that a half of the solarization combined with manure treatment(4) was replaced by solarization with MS (4’) and a half of solarization combined with MS was replaced by solarization combined with manure (5’) . Manure was buried with deeply ploughing followed by irrigation once in solarization treatments and three times in the manure (7).

The experimental design consisted of four years cropping with a complete randomised block with three replicates originally (first year). The treatments were repeated on the same plots for three additional years in two locations instead of three. Single plots were established with a large size (400 to 600m^2). Due to the large differences among the marketable yield variance and that of the control in successive years, the data were converted with logarithmic transformation for statistical analysis. Percentage data were converted with arcsin transformation for statistical analysis. Duncan’s multiple range tests were done for statistical comparison among treatments.

Some small pieces of roots infested by *Fusarium* were buried at 10 and 30 cm of depth before treatments application, and recovered on Komada selective media (Komada 1975) after the treatment to monitor the effect on inoculum. Missing plants were replaced with new ones to keep the plant population.

The incidence of weeds in each treatment was monitored all along the growing season as the time of removing weeds plus cleaning the plants.

Cold stored plants of cv. Pajaro were planted in two-row bed at 30cm apart in the first and fourth years while cv. Camarosa was used at 35cm apart in the second and third years of experimentation. Two variables were used for estimating plant vigour: plant diameter and plant height.

Marketable yield (expressed in g/m^2) and percentage of second quality fruit yield over marketable yield were recorded.

RESULTS

No important pathogens were detected in the soil or plants. Nevertheless, soil fatigue was observed, due possibly to the presence of a fungal complex in which *Fusarium* spp participates as a main component. Results on survival of *Fusarium* spp from small pieces of roots (Table 1) show that control and manure treatments do not destroy inocula, independently of the depth of sampling. VIF and improved solarization treatments are effective on the surface, but not as much as standard MB in depth. Only standard MB treatment eliminated completely the inoculum. However, solarization combined with manure (4) is promising in this aspect, too. The efficacy of solarization with MS has declined in the fourth year with respect to the first one. The sub-treatments (4’ and 5’) applied in the fourth year did not improve the fungicidal efficacy of the disinfestation.

Table 1. Survival percent of *Fusarium* after disinfestation, from biological probes.

Year	1998		1999		2000		2001	
Treatment	10cm	30cm	10cm	30cm	10cm	30cm	10cm	30cm
1 Control	100	100	100	100	100	100	100	100
2 MB60	0	0	0	0	0	0	0	90
3 MB30VIF	0	2.5	5	50	0	100	0	5
4 Sol.+Manure	0	22.5	5	10	0	60	0	20
4’ SolMV							25	90

Year	1998		1999		2000		2001	
Treatment	10cm	30cm	10cm	30cm	10cm	30cm	10cm	30cm
5 Sol.+MS	12.5	50	0	55	0	50	20	45
5' SolVM							40	60
6 MS	12	40	10	75	0	50		
7 Manure 15	100	100	100	100				

Solarization combined with manure treatment (4) was similar to MB treatments in plant vigour the first two years while solarization combined with MS was similar to that one the first year only. In the following years MB treatments showed better plant vigour than the rest of them. Control and manure treatment (7), when it was applied, produced less vigorous plants. Plant failure and small plant size in manure treatment (7) could be due to phytotoxicity caused by excess manure.

The effect of weeds was significantly higher in manure and control. From the point of view of weed control, all other treatments had a similar effect as MB treatments along the experiment.

Results concerning earliness are not fully representative because of the variability in environmental conditions from one year to another (cold temperatures in winter 1998-99, severe drought in 1999-2000, and early high temperatures and drought in 2000-2001). Despite these abnormalities, there is a slight trend to increase earliness in the improved solarization treatments if we take into account the results in a global manner.

Results of marketable yield and percentage of second quality fruit yield are shown in Table 2. Duncan multiple range tests for marketable yield can offer us an approach about the efficacy of every treatment although they had to be done for each year independently because of the change of the variety and the large differences in climatic conditions from one year to other.

Table 2. Marketable yield and % of class 2 quality fruit yield over marketable along the four years.

	Marketable yield (g/m^2)				% Second quality fruit yield			
Treatment	1998	1999	2000	2001	1998	1999	2000	2001
1 Control	2325 c	2039 c	1150 c	603 d	16.2 c	23.1 b	27.7 e	20.5 c
2 MB60	3956 a	3835 a	2852 a	3076 a	8.5 a	14.6 a	12.3 a	10.9 a
3 MB30VIF	3735 a	3547ab	3123 a	3048 a	8.6 a	13.9 a	13.1 a	11.4 a
4 Sol.+Manure	4090 a	3011ab	2029 b	1553 bc	10.3 a	18.3 ab	21.0 d	19.0 bc
4' SolMV				1464 c				15.7 b
5 Sol.+MS	4028 a	2815 b	2014 b	1803 bc	9.7 a	18.9 ab	18.5 cd	16.5 b
5' SolVM				1973 b				17.0 bc
6 MS	3104 b	2131 c	1924 b		11.3 ab	23.3 b	19.5 cd	17.7 bc
7 Manure 15	2069 c	1003 d			15.1 c	34.2 c		

Regarding marketable yield, we can observe that the more stable treatments are those based on MB although all treatments seem to decline in productivity along the years.

Solarization with manure treatment does not differ significantly from MB treatments in the first two years. Nevertheless, it moves to a group of classification different from MB in the last two years. Solarization combined with MS belongs to the MB group of classification the first year only.

Results of MS treatment occupied an intermediate position while it was applied. Solarization improved with MS, even at reduced dosages works better than standard MS always. The worse results were obtained with the control (1) and manure (7) treatments. If we take into account the results of marketable yield for 4, 4' , 5 and 5' treatments in the last year, we realise that the effect of replacing manure for MS (4') is worse than that one caused by the replacement of MS for manure (5'). In fact, differences between treatments 4 and 5 are not significant in the last year while differences between treatments 4' and 5' are significant. With respect to solarization combined with MS at the dosage used in this research, results were not promising after four consecutive years of application on the same plot. Maybe this lack of effectiveness could be corrected by increasing the dosage of this fumigant.

Regarding second quality fruit yield, results indicate that MB treatments offered the lower percentage and the higher stability as well. Improved solarization treatments remain at the same level as MB in this aspect in the first two years only. The worse treatments were manure and control.

CONCLUSIONS

After four years of research, we can infer that improved solarization with manure offers the better possible alternative when data of the first two years are considered but there is a loss of efficacy if these treatments are uninterruptedly applied longer than two years. The effect of replacing MS for manure had less marketable yield losses than the reverse replacement. The only treatment that gives similar results to standard MB in marketable yield, and fruit quality is the MB 30g/m^2 with VIF sheet. This treatment allows us to follow the EU regulations of reducing consumption of MB up to its phase out.

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NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE FOR THE CONTROL OF ROOT-KNOT NEMATODES IN SOUTHERN ITALY

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ABSTRACT

Soil solarization with different plastic films and inorganic (sulphur) or organic (olive pomace and chicken manure) soil amendments were used, alone or in combination, for the control of *Meloidogyne incognita* on cantaloupe and tomato in two field trials in Southern Italy. Soil solarization positively affected cantaloupe yield and suppressed soil nematode population in the soil. No differences were found between the different plastic films. Sulphur alone was beneficial for yield and nematode suppression at all the tested rates, but no further yield and suppressivity increase was derived from its combination with soil solarization. Olive pomace and chicken manure as single treatments significantly increased tomato yield and suppressed *M. incognita* population, whereas their combination resulted in further positive effects only at the highest rates.

Keywords: cantaloupe, tomato, root-knot nematodes, soil amendments, solarization, integration.

INTRODUCTION

Use of organic and/or inorganic amendments could represent one of the possible alternatives to chemicals in the control of root-knot nematodes, *Meloidogyne* species (D'Addabbo 1995; Rodriguez-Kabana 1986). Moreover, the combination with soil solarization could enhance the nematicidal action of these amendments (Gamliel & Stapleton 1993; Greco *et al.* 1992). Two field trials were carried out in 1999-2000 to verify the suppressivity of some organic (olive pomace and chicken manure) and inorganic (sulphur) amendments largely available in Southern Italy, alone or combined with soil solarization, on *Meloidogyne incognita*.

MATERIALS AND METHODS

In a first experiment, a field infested by *M. incognita* was subdivided in 2 x 5 m plots, which were then solarized from June to August 1999 with 0.050 mm polyethylene or 0.035 mm EVA films and/or treated with three different doses (500, 750 and 1,000 kg/ha) of a 90 % sulphur formulation. Four replicates were provided for each treatment, according to a randomized block design, and untreated soil served as control. Cantaloupe (cv. Gialletto Rugoso di Cosenza) was cultivated in the plots from May to August 2000.

In the second trial, another *M. incognita* infested soil, arranged in 3 x 4 m plots, was amended with fresh olive pomace at the rates of 25, 50 and 100 T/ha and/or chicken manure at 1, 2 and 4 T/ha in January 1999. A dosage of 300 kg/ha of granular fenamiphos and untreated soil served as control. One month old tomato (cv. Tondino) seedlings were planted in the plots in the next May. In both experiments, crop yield was recorded and the final nematode population was determined in the soil.

RESULTS AND DISCUSSION

In the first experiment, the yield of cantaloupe was significantly increased by soil solarization with or without sulphur and by sulphur as single treatment. The thickness of the polyethylene did not affect the yields, which were significantly increased by EVA 0.150 mm, compared to EVA 0.035 mm. The addition of either 750 or 1,000 kg/ha sulphur previously to soil solarization was beneficial compared with the polyehylene tarping only. The sulphur application under EVA tarping did not statistically increased the yield with respect to 500 kg/ha sulphur alone (Table 1). The nematode population was significantly suppressed by either solarization or sulphur treatments: No difference was found between the two films or among the sulphur dosages and no further suppression derived by the combined use of solarization and sulphur.

In the second experiment, olive pomace and chicken manure significantly increased tomato yield and reduced *M. incognita* population in the soil, compared to untreated control, at all the tested dosages (Table 2). Combinations of 100 T/ha olive pomace with 2 and 4 T/ha chicken manure resulted in a further yield increase and were more suppressive than fenamiphos on *M. incognita*.

In conclusion, sulphur application, either alone or combined with solarization, could represent a further possible alternative for integrated nematode pest management. The suppressivity of olive pomace and chicken manure, either alone or combined, was previously reported in other experiments (D'Addabbo & Sasanelli, 1996;

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Table 1: Effect of soil solarization and sulphur on *Meloidogyne incognita* on cantaloupe.

Sulphur (kg/ha)	Soil solarization	Crop yield (T/ha)		Final nematode population (Eggs and J2/ml soil)	
-	-	12.6	ab*	11.7	a
500	-	16.4	b	3.2	c
500	Polyethylene 0.050 mm	16.2	b	3.1	c
500	EVA 0.035 mm	19.0	bc	2.9	c
750	-	17.8	bc	4.3	c
750	Polyethylene 0.050 mm	20.4	c	2.6	c
750	EVA 0.035 mm	20.2	c	4.3	c
1000	-	17.0	bc	3.7	c
1000	Polyethylene 0.050 mm	20.4	c	3.4	c
1000	EVA 0.035 mm	20.4	c	1.6	c
-	Polyethylene 0.050 mm	17.0	bc	2.1	c
-	EVA 0.035 mm	16.4	b	4.9	bc

* Means followed by the same letters in the same column are not significantly different according to Duncan's Multiple Range Test (P = 0.01).

Table 2: Effect of olive pomace (FOP) and chicken manure (CM) soil amendments on *Meloidogyne incognita* on tomato.

Treatments	**Crop yield (T/ha)**		**Final nematode population (Eggs and J2/ml soil)**	
Untreated control	44.8	a*	49.1	a
Fenamiphos 300 kg/ha	65.0	def	20.7	cdef
FOP 25 T/ha	57.1	bcd	27.6	bc
FOP 50 T/ha	53.0	ab	26.8	cd
FOP 100 T/ha	56.5	bcd	25.5	cde
CM 1 T/ha	53.5	ab	37.9	b
CM 2 T/ha	54.3	bc	26.1	cd
CM 4 T/ha	53.8	bc	20.4	cdef
FOP 25 t/ha + CM 1 T/ha	56.5	bcd	25.4	cde
FOP 25 t/ha + CM 2 T/ha	56.1	bcd	23.2	cde
FOP 25 t/ha + CM 4 T/ha	60.5	bcd	23.0	cde
FOP 50 t/ha + CM 1 T/ha	60.8	bcd	20.4	cdef
FOP 50 t/ha + CM 2 T/ha	63.3	cde	21.0	cdef
FOP 50 t/ha + CM 4 T/ha	61.0	bcd	20.6	cdef
FOP 100 t/ha + CM 1 T/ha	64.1	def	16.0	def
FOP 100 t/ha + CM 2 T/ha	73.8	f	14.5	ef
FOP 100 t/ha + CM 4 T/ha	71.8	ef	11.3	f

* Means followed by the same letters in the same column are not significantly different according to Duncan's Multiple Range Test (P = 0.01).

NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE IN URUGUAY

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ABSTRACT

Methyl bromide (MB) is used in Uruguay on vegetable crops, tobacco, cut flowers and seedbeds. MB consumption increased from 4 t in 1993 to some 59 t in 2000, equivalent to a 15-fold increase. Non-chemical alternatives to MB are reported, based on the use of biofumigation, solarization, resistant varieties and crop management that farmers are already applying. Results confirm that MB is not necessary in vegetable and strawberry crops in Uruguay. MB phase out is urgent because of the risk that this chemical represents to workers and farmers.

Keywords: nematodes, biofumigation, solarization, resistant varieties, agro-ecology

INTRODUCTION

Methyl bromide (MB) is used in Uruguay by horticulture under greenhouse, cut flowers and substrate disinfections in seedbed preparation. According to the General Direction of Agricultural Services from the Agricultural-Grazing-Fishery Ministry (GDAS), the volumes imported increased significantly from 40,189 kg imported in 1999 to 58,506 kg in 2000 following a crescent trend for this year. It is remarkable that by 1997 the amount of MB imported was less than 10 tonnes and in 1993 it was around 4 tonnes (MBOTC 1995).

In most of Uruguayan crops there is no use of MB. It is used in tomato, pepper, cucumber and melon which are cultivated under greenhouse mainly in Salto, as well as in tobacco nurseries in Artigas. MB use in Uruguay is unusual and it is restricted to areas of intensive horticulture. Notably, Uraguay is one of the very few countries in which strawberries are produced without MB. For all these reasons, we consider that Uruguayan experiences should be better known and could be used as examples for other regions (De León & Peyrou 2000).

Among sanitary problems caused by soil pathogens that affect intensive horticulture that leads to the use of MB as a control measure, we find damage caused by nematodes belonging to *Meloidogyne* genus *(M. arenaria* and *M. incognita*). Monoculture, temperature and moisture increases in crops grown under greenhouses, the intensive use of pesticides and fumigation products, the incorrect use of resistant varieties have together made phytosanitary problems worse.

Among non-chemical alternatives there are solarization and biofumigation, besides a variety of agricultural practices, resistant varieties, biological control agents (Casanello *et al*. 2001; De León *et al*. 2000abc; 2001ab); and among chemical ones dazomet and metam sodium are used (INIA-ONUDI 2001).

NON CHEMICAL ALTERNATIVES

Biofumigation was evaluated in Uruguay using different organic crop remnants, green manures, resistant varieties and other agricultural techniques under an integrated production system.

Biofumigation

One of this alternatives which is being developed with success in many countries and in Uruguay is biofumigation, defined as: “The action of volatile substances, produced by organic matter bio-decomposition, in plant’s pathogens” (Bello *et al.* 2000 a, b). The use of this materials helps either to solve the environmental problems generated by organic crop remnants. This technique is cheap and easy to put into action, and combined with other practices such as solarization it may become more efficient by means of enabling it’s application in different seasons and areas with optimum temperatures, despite temperature is not a limitation variable. Biofumigation success is enhanced when included in an integrated crop management system. A wide variety of materials have been tested as soil amendments that are useful for control of nematodes, fungi and weeds.

Since 1996 there have been carried out evaluations in several crops and productive regions from Uruguay about the effects of biofumigation in controlling nematodes belonging to *Meloidogyne* genus. The success of this practice have been confirmed in Tacuarembó for salt-wart and tomato crops, and in Montevideo and Canelones for tomato crops. Besides we consider that biofumigation effects are the key factor in the low incidence of nematodes and other soil pathogens in horticultural crops located in Bella Union, Canelones, Montevideo and other areas (De León *et al.* 2000abc; 2001ab).

In the trials, different biofumigants were tested which reached similar efficiency and in some cases better than conventional chemical phytosanitary products. Tested were: chicken dung with rice husk, hen dung with rice husk, cattle and sheep dung, rice husk, broccoli, corn and other agro-industrial residues (Bello *et al.* 1999; 2000ab). The difference with the pesticides available in the market is that they do not have negative effects neither over the environment nor over people's health (consumers and farmers). Furthermore, biofumigants do not have restrictions applied in integrated production systems or ecological agriculture.

Additionally we want to point out that using agricultural residues, which are an excellent organic matter source, is to make them work both as soil improvers and as soil pathogen controllers. In that way the amount of soil nutrients increases improving soil productive capacity by means of a higher offer of available nutrients for plants. Soil structure is also ameliorated, promoting permeability and aeration resulting in increased effectiveness of organic fertilization, it increases microorganism activity and biological soil process associated, both by population growth and enrichment of biodiversity.

Uruguay is carrying out a project to develop alternatives to MB as well as to avoid its use. It began in 1999 and its results had been exposed recently confirming the existence of alternatives as biofumigation which achieves similar or better performance than MB in pathogen control, using several organic materials: rice husk, chicken dung with rice husk, broccoli, sweet corn and cauliflower residues (INIA-ONUDI 2001).

The search for alternatives for MB is not only for environmental and human health reasons, but also for economic ones. The application of MB in 1000 m^2 of greenhouse, at its recommended doses of 100 g/m^2, costs US$710. On the contrary, biofumigation for the same area costs US$75 including labour.

Solarization

Solarization is used in horticultural regions from Salto and Bella Unión, and is a way of soil pasteurizing using summer sun radiation to increase soil temperatures. It is implemented by covering previously humidified soil with transparent nylon during the warm season. This technique had obtained a variable efficiency to control nodule producer nematodes (*Meloidogyne)* (De León *et al.* 2000 c; Casanello *et al.* 2001).

Resistant varieties

The use of resistant varieties is being applied in tomatoes, but it is necessary to take into account that resistance may not be effective when the soil temperature is high, when the plant roots are attacked by fungi, or more frequently, when resistant plants are exposed to virulent populations.

It has been reported that tomato varieties with *Mi* gene, which awards resistance against nodule producer nematodes (*Meloidogyne arenaria, Meloidogyne incognita and Meloidogyne javanica),* are very affected by those pathogens and, in some cases, even making the crop unfeasible. This occurs recurrently in northern Uruguayan departments, specially Salto and Artigas, where soil temperatures often exceed 27 ºC, one of chief ways resistance is broken.

This situation is serious since resistant varieties have been considered as a major alternative to MB. Several populations of *Meloidogyne incognita* coming from resistant tomato plants roots have been studied and it was find that they maintained their virulence in chambers with temperatures under 25ºC. This leads us to think that conventional cropping practices are contributing to the selection of virulent populations which could make resistant varieties non-viable in the future (De León *et al*. 2001 a).

Other cropping practices

The most frequently used are organic residue mulching, in order to regulate soil temperature, reducing the length and number of *Meloidogyne* genus nematodes cycles while dropping the number of adventitious plants. It is of major importance to design integrated production systems, with crop rotation, introducing brief cycle crops, such as lettuce, that function as trap plants. It is also important to accurately plan the planting time and sanitary procedures in order to lessen pathogens risks.

CONCLUSIONS

Biofumigation has a similar efficiency as conventional pesticides for controlling vegetable soil pathogens, with the additional benefit of improving soil and plant qualities. The methodology required to put biofumigation into practice under commercial field conditions is approachable for both technicians and farmers. Its success is enhanced when included as part of an integrally managed production system.

We consider that the obtained results show that there are effective alternatives to MB tested in different productive regions of Uruguay. Biofumigation, due to its efficiency and low cost, is becoming the principal alternative practice in different productive areas in Uruguay. It is necessary to bring forward the date of MB elimination in order to reduce its deleterious impact on farmer and worker health and on the environment.

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INFLUENCE OF PREPLANT SOIL FUMIGATIONS ON *TRICHODERMA* POPULATIONS IN STRAWBERRY PRODUCTION FIELDS

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ABSTRACT

This paper is part of the national project INIA SC 97-130 on methyl bromide (MB) alternatives for preplant soil fumigation on several crops, among them the strawberry crop. Several treatments were tested over three years at two places in Huelva province. The influence of these treatments on *Trichoderma* populations was evaluated by soil isolated onto selective media. These populations have been increased year after year and significant differences were detected between the treatments and the control. The major populations were observed after MB treatments.

Keywords: methyl bromide, strawberry, *Trichoderma*.

INTRODUCTION

The field trials and laboratory assays reported are part of the national project INIA SC 97-130 on methyl bromide (MB) alternatives for preplant soil fumigation on strawberry crop. Several treatments were tested for over three years at two locations in Huelva (southern Spain), where more than half the strawberry acreage in Spain is situated (Hancock 1999). The majority of the hectarage is under small tunnels for early production of fresh market fruit. Plants are grown in intense annual systems on raised beds with preplant fumigation (López - Aranda & Bartual 1999), basically using broad-spectrum fumigants as MB and chloropicrin. Because of the use of MB for years, Huelva soils show low levels of soil pathogens, but crop yields are better in fumigated soil than in not fumigated ones.

Species of *Trichoderma* are primarily studied for their ability to control plant disease through mycoparasitism and/or the production of antimicrobial compounds (Bailey & Lumsden 1998). These species can affect plant growth (Lindsey & Barker 1967; Wright 1956). Determination of these effects depend on many interactions that take place in the soil between *Trichoderma* spp., other microorganism, changes in the soil environment, and the plant root (Bailey & Lumsden 1998). Soil fumigations affected the environment and induced variations on *Trichoderma* populations, and after MB treatments these fungi can reproduce rapidly (Munnecke *et al.* 1981). The objective of this report was study the native *Trichoderma* after different fumigations.

MATERIALS AND METHODS

Two field trials were carried out at two locations in Huelva: Moguer (eastern coast) and Cartaya (western coast). The design of each experiment was in randomized block with three replicates. Fumigations (Table 1) were applied before planting with cv. "Camarosa".

Soil samples were taken after fumigations by a vertical graduated drill (0-20 cm). Samples were air dried. 10 g of soil was suspended in 99 ml of agar (0.3%) distilled water medium, shaken for 15 minutes and 0.1 ml aliquots were spread on Petri dishes with *Trichoderma* Selective Medium (TSM) with a glass rod (Elad *et al.* 1981). Plates were incubated for 7 days at 25°C.

Mean separation of data was analysed according to the least significant difference, calculated on square root transformed data using Newman and Keuls test, at $P < 0.05$.

TABLE 1: Fumigants treatments.

Treatments	Description
Control	Control without disinfestation
MB (20) Pref. Beds VIF	MB-Pic. (50/50) 20 g/m^2 preformed beds black VIF
MB (40) Pref. Beds	MB-Pic. (50/50) 40 g/m^2 preformed beds
Telone C-35 (40)	Telone C-35 telopic 40 cc/m^2 preformed beds
Metam S 175	Metam Sodium 175 cc/m^2 preformed beds
Dazomet (50)	Dazomet 50 g/m^2 preformed beds
Chloropicrin (40)	Chloropicrin 40 g/m^2 preformed beds

RESULTS

Tables 2 and 3 show the results obtained after the treatments. In the first year, the number of *Trichoderma* spp. propagules was the lowest, without significant differences between the control and the treatments. After one crop and two treatments, soils fumigated with MB or Telone showed important populations of *Trichoderma* spp., with significant difference in all cases between MB and the control, but there were no significant differences between MB doses. The same effect was observed incremented in the last year.

When soil was treated with Metam Sodium or Dazomet the number of propagules was very low or zero. The exception was observed at Tariquejo in the last year as there were problems of humidity on pre-plant dip irrigation at the moment of Dazomet incorporation.

Figure 1 shows the evolution of *Trichoderma* population. After repeated treatments with MB, Telone and chloropicrin the number of popagules increased year by year.

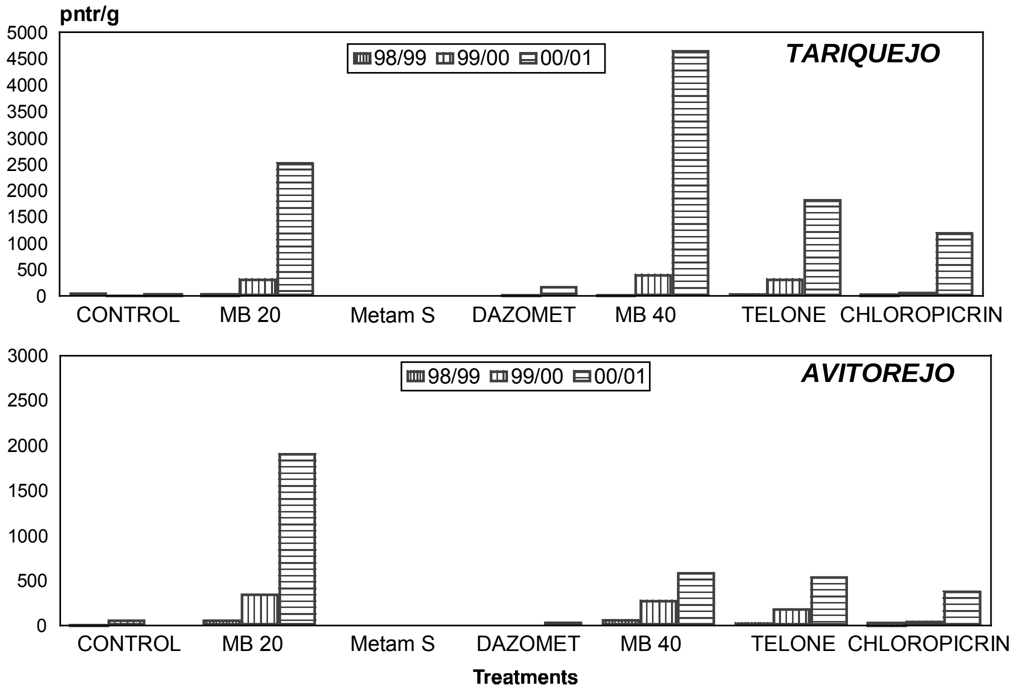
TABLE 2: Propagules number of *Trichoderma* spp. per gram of soil (pntr/g) (Tariquejo)

	pntr/g		
Treatments	**1998/99**	**1999/2000**	**2000/01**
Control	66.0 a	6.6 b	39.6 c
MB (20) VIF	33.0 a	336.6 a	2534.7 ab
MB (40)	13.2 a	415.8 a	4657.0 a
Telone C-35 (40)	52.8 a	336.6 a	1831.7 ab
Metam S 175	0 a	0 b	0 c
Dazomet (50)	0 a	19.8 b	188.12 bc
Chloropicrin (40)	26.4 a	79.2 b	1207.9 abc

TABLE 3: Propagules number of *Trichoderma* spp. per gram of soil (pntr/g) (Avitorejo)

	pntr/g		
Treatments	**1998/99**	**1999/2000**	**2000/01**
Control	6.6 a	66.0 bc	0 b
MB (20) VIF	66.0 a	356.43 a	2801.9 a
MB (40)	72.6 a	287.13 a	594.0 a
Telone C-35 (40)	33.0 a	191.4ab	544.5 ab
Metam S 175	0 a	0 c	0 b
Dazomet (50)	0 a	0 c	39.6 b
Chloropicrin (40)	26.4 a	52.8 bc	386.1ab

Figure 1.- Evolution of *Trichoderma* populations for three years.



CONCLUSIONS

Some fumigants such as MB, Telone or chloropicrin induced an increase of *Trichoderma* spp. in soils. These organisms could affect the plant growth and it could be an explanation for the beneficial effect of MB over the strawberry crop.

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QUARANTINE TREATMENT OF STORAGE INSECT PESTS UNDER VACUUM OR CO_2 IN TRANSPORTABLE SYSTEMS

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ABSTRACT

The objective of our investigation was to identify the combinations that enhance the effectiveness of insect control, based on vacuum or CO_2 in combination with increased temperatures, as a quarantine treatment to control storage pests. In laboratory studies with *Lasioderma serricorne* exposed to low pressures at 30ºC, LT_{99} value for adults was 15 h when exposed to 25 mm Hg. *Trogoderma granarium* diapausing larvae were the most resistant species, requiring 172 h exposure under the same conditions. The effect of CO_2 at 45°C for reducing the exposure time for diapausing larvae of *T. granarium* showed that, by increasing the CO_2 concentration to 90%, the LT_{99} decreased to about 10 h, whereas at 35ºC the LT_{99} value was 29 h. *Ephestia cautella* larvae were shown to be the most resistant stage to 90% CO_2 at 40°C, with an LT_{99} value of only 6 h. For *Oryzaephilus surinamensis* under the same conditions, the LT_{99} value was 9 h for the most resistant egg stage. These encouraging results led to the idea of developing a transportable flexible storage system to render the technology a practical tool for the control of insect pests. Experiments were carried out using a 15m^3 plastic container termed the "Volcani Cube™" or "GrainPro Cocoon™". Bioassay field trials demonstrated that complete mortality of test insects composed of all four developmental stages of *E. cautella* and *Tribolium castaneum* was observed when exposed to a vacuum for 3-days.

Keywords: quarantine treatment, methyl bromide, alternatives, vacuum, CO_2, storage insects, transportable systems, *Trogoderma granarium*

INTRODUCTION

Although there are a number of suggested potential chemical and non-chemical alternatives to methyl bromide (MB), each has limitations that prevent it from being a direct replacement for MB in all its current uses (Bell *et al*. 1996). Controlled atmosphere (CAs) can fulfill a specific niche where use of other fumigants is unacceptable such as treating organic foods. CAs are limited by the long exposure times required to produce complete mortality (Navarro and Jay 1987), and are similar to those required for phosphine (PH_3) fumigations (Navarro and Donahaye 1990). In cases where rapid disinfestation of commodities is required, the possibility of using CO_2 at temperatures raised to levels that will not adversely affect the commodity should be considered.

Investigations on effects of low pressures on storage insects were carried out by Back and Cotton (1925), Bare (1948), and later on by Calderon *et al*. (1966), and Navarro and Calderon (1969; 1972a; 1972b). Recently Mbata and Phillips (2001) investigated the effects of temperature and exposure time on mortality of three stored product insects exposed to low pressure. Insect mortality under low pressure is predominantly a result of oxygen deficit and not due to physical pressure effects (Navarro and Calderon 1979).

In a first attempt to use low pressures to preserve cacao beans quality, Challot and Vincent (1977) used polyethylene bags applying a low pressure of 600 mm Hg. Although 600 mm Hg may be effective in maintaining the product quality and prevent ingress of insects, storage insects can tolerate this pressure. For mortality of storage insects, low pressures below 100 mm Hg are required.

Gas tight flexible structures using the hermetic storage method have been developed and are in use on an industrial scale (Navarro *et al.* 1988; 1994; Navarro *et al.* 1990). These structures enable the treatment of modified atmosphere or fumigation (Navarro *et al.* 1995), and they are termed “Volcani Cubes™” or “GrainPro Cocoons™” (Navarro *et al* 1999). The use of these flexible storage facilities to maintain low pressures of 25-30 mm Hg was reported recently (Phillips *et al*. 2000; Navarro *et al*. 2001).

This paper reports on the effects of exposure time and treatment temperature on the mortality of different life stages of stored product insect pests exposed to increased temperatures and a constant low pressure or under a CO_2 enriched atmosphere, and it reports on the application of transportable systems that use these combinations for quarantine treatments.

MATERIALS AND METHODS

Temperature, low pressure and CO_2 combinations

For low-pressure treatments, absolute pressures of 25, 50 and 100 mm Hg at temperatures varying from 18° to 35ºC were tested. For CO_2 treatments, concentrations varying from 60% to 90% of CO_2 in air at temperatures varying from 30° to 45°C were tested.

Test insects

Diapausing larvae of Khapra beetle *(Trogoderma granarium)* were obtained by holding active larvae without food for one month at 28ºC (Lindgren and Vincent 1960). Adults of *Oryzaephilus surinamensis, E. cautella* and *Lasioderma serricorne* were taken from laboratory cultures reared on standard artificial diet. Eggs (0-2 days old), pupae and adults (1-2 days old) and larvae (4-15 days old) were taken from the same batch. Two Perspex slides each with 50-drilled "wells" were used to individually place 100 eggs from each of the studied species (Navarro and Gonen 1970). Following treatment, larvae, pupae and adults were transferred to small jars (50 ml) and maintained at 28±1°C and 65±5% r.h. Adults and larvae were provided with food.

Statistical analysis

To determine the lethal time to obtain 99% mortality (LT_{99}) data were subjected to probit analysis (Daum 1979). Results in this paper are presented without detailed statistical analysis to show the ranges of exposure times needed to control the test insects.

Application of the technology

The tested transportable system was made of flexible PVC which had been in use commercially for hermetic storage of commodities to control insect disinfestation by modified atmospheres (Navarro *et al.* 1999). Experiments were carried out using a 15-m^3 capacity plastic container called the “Volcani Cube™” or “GrainPro Cocoon™”. The pressure was maintained between 25 to 29 mm Hg and bioassay consisted of all four developmental stages of *E. cautella* and *T. castaneum*.

RESULTS AND DISCUSSION

Effects of low pressures and increased temperatures

Table 1 shows partial results obtained on three developmental stages of *L. serricorne*. Although the LT_{99} value for *L. serricorne* adults exposed to 25 mm Hg at 30ºC was 15 h, there is an apparent resistance of this species to low pressures. Eggs exposed to 25 mm Hg even at 30^0C needed 75 h exposure to attain LT_{99} value. Bare (1948) also observed greater tolerance of *L. serricorne* eggs compared with other stages exposed to low pressure. Mortality values for diapausing larvae of *Trogoderma granarium* are shown in Table 1. When the pressure was decreased to 25 mm Hg and the temperature raised to 35°C, the LT_{99} value was 146 h; at 30°C under the same pressure, it was 172 h. These lengthy exposures are comparable with 6 and 7-day exposures required for phosphine fumigation (Navarro and Donahaye 1990). These findings may also be compared to those of Calderon and Navarro (1968), on non-diapausing larvae at 25ºC and 65% rh, where complete mortality was obtained within 120 h exposure to 20 mm Hg.

Effects of CO_2 and increased temperatures

Table 2 shows the effectiveness of the combination of CO_2 at temperatures in the range of 35ºC to 45ºC on *Ephestia cautella.* The pupa was the most resistant stage when exposed to 90% CO_2 with an LT_{99} value of 17 h at 35ºC, and only 3 h when exposed at 45ºC. The adult was the most sensitive stage of *E. cautella* requiring only 4 h of exposure to 90% CO_2 at

35ºC. Results on *O surinamensis* developmental stages show that increasing the CO_2 concentration resulted in decreasing the LT_{99} value. Generally, the eggs were the most resistant stage; at 40ºC and 90% CO_2 a six h exposure was required for an LT_{99} value. Mortality values for diapausing larvae of *T. granarium* at 45°C show that increasing the CO_2 concentration to 90%, the LT_{99} value decreased to 10 h, whereas at 35ºC the LT_{99} value was 29 h.

T. granarium is one of the most serious pests of stored cereal grains and oil seeds, and is subject to strict quarantine regulations in the US, Australia and several other countries. It is a voracious feeder of grain products. The larvae can hide in cracks of the storage structure in a state of facultative diapause and can remain in this condition for years. It is particularly difficult to control with insecticides. Consequently, many quarantine treatments are mandatory when products such as rugs, spices and cereal products are imported from infested countries. In such situations, MB is still the only effective fumigant against this pest. Present distribution of *T. granarium* includes Western Africa through the Northern Indian subcontinent. Results shown in Table 2 may serve as guidelines to the possibility of applying increased temperatures for the quarantine treatment of the most resistant diapausing larvae of *T. granarium.*

TABLE 1: Effects of temperature and low-pressures on LT_{99} (hours to obtain 99% mortality) values for *Lasioderma serricorne* at various development stages and for *Trogoderma granarium* diapausing larvae.

Pressure (mmHg)	Temperature (ºC)	*Lasioderma serricorne*			*T. granarium*
		Eggs	Larvae	Adults	Diapausing larvae
25	18	-[1]	-	47	-
	25	-	-	26	>360
	30	75	-	15	172
	35	-	-	-	146
50	18	-		157	-
	25	-	191	43	>360
	30	-	49	15	260
	35			-	>360
100	18	136	-	-	-
	25	75	-	75	>360
	30	40	-	-	>360
	35	-	-	-	>360

[1] Data not available

Rigid metal chambers have been in use for the implementation of vacuum fumigation in agricultural commodities (Bond 1984). These structures are expensive and are not easily transportable. In order to render the technology practical, the possibility was recently investigated of using CO_2 or low pressures to control storage insects in a transportable system (Phillips *et al*. 2000). Bioassay in field trials at 22° to 25°C demonstrated that complete mortality of test insects composed of mixed ages of *E. cautella*, and *T. castaneum* was possible following 3-days exposure to vacuum. For quarantine treatments of durable commodities, these flexible storage containers could be considered useful for applying vacuum or CO_2 as alternative methods to MB or other toxic fumigants.

TABLE 2: Effects of temperature and CO_2 concentrations in air expressed in LT_{99} (hours to obtain 99% mortality) values for *Ephestia cautella* and *Oryzaephilus surinamensis* at various development stages and for *Trogoderma granarium* diapausing larvae.

Insect species	Temp. (°C)	30				35				40				45			
	CO_2 (%)	60	70	80	90	60	70	80	90	60	70	80	90	60	70	80	90
Ephestia cautella	Eggs	-[1]	-	-	-	23	23	17	9	16	12	8	5	9	5	3	2
	Larvae	-	-	-	-	60	27	20	12	17	9	6	6	5	4	2	2
	Pupae	-	-	-	-	56	37	17	17	36	10	8	4	7	4	4	3
	Adults	-	-	-	-	20	14	6	4	6	5	3	2	3	2	2	2
Oryzaephilus surinamensis	Eggs	-	-	38	22	29	25	22	9	15	7	6	6	-	-	-	-
	Larvae	-	-	-	-	-	-	-	-	8		2	2	-	-	-	-
	Pupae	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-
	Adults	21		22	9	26	11	8	4	12	11	6	3	-	-	-	-
T.granarium	Diapausing larvae	-	-	-	-	38	29	-	-	24	28	20	-	15	17	15	10

[1] Data not available

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METHYL BROMIDE ALTERNATIVES FOR CARROTS AND OTHER VEGETABLE CROPS IN NORTHWEST COAST OF CADIZ (SPAIN)

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ABSTRACT

Carrot are produced on about 2,900 ha in the Cadiz area. Soil-borne problems are root-knot nematodes, *Pythium* sp., "cavity spot" and nutsedges. Field experimental design was randomized blocks with three replicates. Chemical (MB, Telone-C17, PIC, Telone II), non-chemical (solarization + biofumigation) and mixed (solarization, + metam-sodium + Telone II) treatments started in July 1997. Four carrot cultivations were carried out between October 1997 and May 1999. The final experiment was carried out on potato (August-December 1999). Good sanitary conditions were evident. The results suggest alternatives to MB exist for carrot and other vegetable crops produced in the Cadiz area.

Keywords: carrot, potato, chemical, non-chemical, alternatives, solarization, biofumigation, metam-sodium, nematodes

INTRODUCTION

Cut-flowers are mainly produced on about 900 ha of coastal area near Cadiz in Spain. These cut-flower cultivations under plastic greenhouses are carried out in very small farms and they are associated with field (open-air) production of several vegetable crops. Field production usually begins in the autumn with cultivation of carrot for the European fresh market. The area of Cadiz has about 2,900 ha of carrot cultivation with typical yields of 5 kg/m^2 of commercial roots. "Mokum" is the most important carrot cultivar in the area. This carrot cultivation is followed by other field vegetable crops like potato, tomato, etc.

Traditionally, the Northwest coastal area of Cadiz has used cold or heat diffusion of MB (98-2) for decades. Soils have a sandy texture and the environment (soil and water) is alkaline. The main pathological soil-borne problems are root-knot nematodes (*Meloidogyne incognita*), *Pythium* sp. and several kind of weeds with very special invasion of yellow nutsedges (*Cyperus* spp.).

The field trials reported are part of the National project INIA SC 97-130 on "Short-term Methyl Bromide (MB) Alternatives for Pre-Plant Soil Fumigation in Several Crops". These real scale experiments have been carried out in several plots located in the Experimental Farm of CIFA-Chipiona (Cadiz). The plots have been cultivated with carrots, potatoes and other vegetable crops for decades where records show the presence of *Meloidogyne incognita, Pythium* sp., carrot "cavity spot", and several kinds of weeds (nutsedges and *Malva* sp.). Experimental design was in randomized complete blocks, with three big replicates of 250 m^2/treatment. Chemical and non-chemical fumigation treatments started in July 1997 (Table 1).

TABLE 1: Soil fumigant treatments in carrots.

Treatments	Description
Control	Control without soil fumigation
MB standard	Standardized cold diffusion MB(98-2), 50 g/m^2
MB VIF	Cold diffusion MB(98-2), 25 g/m^2 under VIF transparent film
Telone C17	Injection 1,3 dichloropropene + chloropicrin, 60 cc/m^2
Chloropicrin alone	Injection chloropicrin, 40 cc/m^2
Telone II VIF	Injection 1,3 dichloropropene, 20 cc/m^2 under VIF transparent film
Soil solarization alone	For 6 weeks

Treatments	Description
Soil solarizat. + MB	Soil solariz. and simultaneous cold diffusion MB(98-2), 10 g/m^2
Soil solarizat. + MS	Soil solariz. and simultaneous emulsion Metam Sodium, 60 cc/ m^2
Soil solarizat. + Telone II	Soil solariz. and simultaneous injection 1,3 dichloropropene, 25 cc/ m^2
Soil solarizat. + Biofumigation	Soil solariz. and simultaneous incorporation 5 kg/m^2 mushroom compost
Soil solarizat.+ cuasi-biofumigat.	Soil solariz. and simultaneous incorporation 3 kg/m^2 chicken manure

After soil fumigation, four carrot cultivations cv. "Mokum" were planted in the same experimental plots, as it is usual in the area. The sowing calendar was as follows. First cultivation: sowing date October, 28th, 1997 and harvest date March, 12th 1998. Second cultivation: sowing date May, 18th, 1998 and harvest date August, 11th, 1998. Third cultivation: sowing date September, 26th, 1998 and harvest date January, 19th, 1999. Fourth cultivation: sowing date February, 10th, 1999 and harvest date May, 18th, 1999. Soil samples were taken before and after fumigation treatments as well as before and after each sowing. In addition, plant carrot samples were taken during the four growing seasons. In all cases, including controls without soil disinfestation, a good sanitary status was evident. Neither root-knot nematodes nor fungi attacks appeared. Agronomic results are presented in Table 2.

TABLE 2: Commercial yield of roots (kg/m^2). Carrot "Mokum". Four cultivations (1997-1999).

Treatments	1º cultiv	2º cultiv	3º cultiv	4º cultiv	Av. four cultivations	Average relative yield
MB VIF	3.44 abc	6.06 a	5.10 ab	3.24 a	4.46 a	108
Solarizat. alone	4.47 ab	4.79 abc	5.02 abc	3.38 a	4.41 a	107
Solar.+ chicken man.	4.73 a	4.91 abc	5.34 a	2.54 a	4.38 ab	106
Telone C-17	3.52 abc	5.62 ab	4.47 abcd	3.40 a	4.25 ab	103
Chloropicrin	3.55 abc	5.27 abc	4.53 abc	3.50 a	4.21 ab	102
Solar.+MB	3.81 abc	5.19 abc	4.91 abc	2.88 a	4.20 ab	102
MB standard	2.56 c	5.93 ab	4.44 abcd	3.56 a	4.12 ab	100
Solar.+ MS	4.48 abc	4.17 bc	4.69 abcd	2.99 a	4.08 abc	99
Telone II VIF	2.96 bc	5.34 abc	4.30 bcd	2.99 a	3.90 abc	95
Solar.+Telone II	3.26 bc	4.43 abc	4.81 abcd	3.01 a	3.87 abc	94
Solar.+ mushroom comp.	3.84 abc	3.71 c	4.24 bcd	2.56 a	3.59 bc	87
Control (no disinf.)	3.70 abc	1.74 d	4.68 abcd	2.86 a	3.25 c	79 $P < 0.05$

In order to confirm these trends, a final experiment with autumn potato, cv. "Jaerla", was carried out in the same soils and experimental design of the previously described carrot trials. The following MB alternative treatments were selected and they were located in the replications that had contained them in the former carrot experiments, with some dosage modifications: Controls without soil fumigation; cold diffusion MB (98-2), 40 g/m^2 under VIF transparent film; soil solarization alone for four weeks (August); soil solarization and simultaneous emulsion with Metam Sodium, 80 cc/ m^2; soil solarization and simultaneous injection of Telopic (Telone C35) 40 cc/m^2; soil solarization and simultaneous biofumigation (5 kg/m^2 of fresh chicken manure). Fumigant treatments began in July, 8th and finished in August, 9th, 1999. Autumn potato dates of planting and harvesting were: August, 13th and December 14th, respectively. Once again, in all the cases a good sanitary status in plants and potato tubers was evident. At the moment of harvesting, tubers were classified in several commercial categories. A summarized report of yield results is presented in Table 3.

TABLE 3: Commercial yield of tubers (kg/m^2). Potato "Jaerla". 1999 results.

Treatments	kg/m^2 harvested	Relative yield
Solarization+ MS	2.80 a	125
Solar.+Telopic	2.53 ab	113
Solar.+ fresh chicken manure	2.45 ab	109
Solarization alone	2.40 ab	107
MB (VIF	2.24 bc	100
Control (no disinf.)	1.81 c	81 P < 0.05

These results suggest that several chemical and non-chemical alternatives to standardized cold or hot diffusion MB (98-2), 50 g/m^2 are able to maintain adequate sanitary and productivity levels on carrot cultivation and other field-grown vegetable crops in the Northwest coastal area of Cadiz.

METHYL BROMIDE ALTERNATIVES EVALUATED IN STRAWBERRY PRODUCTION IN UNEP'S REGIONAL DEMONSTRATION PROJECT IN CENTRAL AND EASTERN EUROPE

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ABSTRACT

A two year evaluation of the chemical (dazomet, 1,3-D+CP, metam sodium) and the biological (*T. viride* B35, *P. fluorescens* PSR21) alternatives for methyl bromide (MB) was conducted in three commercial strawberry farms in Poland. The tested alternatives were applied separately or in combinations. All the chemical agents were applied for preplant soil fumigation according to the recommended procedures. The tested biocontrol agents were used for dipping the root system of the plantlets just before the planting. In the experiments, the performance of all the evaluated alternatives was inferior to MB. However, taking into account the improvements in the plant vigour and in the productivity related to the use of some alternatives, 1,3-D+CP at a higher rate (500 l/ha) as well as combination of *T. viride* B35 with reduced dosage of 1,3-D+CP (375 l/ha) can be considered as a possible replacements for MB. Nevertheless, supplementary application of herbicides will be necessary. Metam sodium at the highest doses (1,500 l/ha) alone or combined with the biocontrol agents controlled the Verticillium wilt, but its effectiveness was not acceptable for commercial reasons. Dazomet did not significantly improve the productivity of strawberry fruits and runners. However, in the absence of the major soil-borne pathogen (*V. daliae*) the application of dazomet as well as metam sodium combined with *T. viride* gave a similar improvement of the fruit production as MB. Moreover, the efficacy of biocontrol agents applied separately was inconsistent.

Keywords: strawberry, soil treatment, transplant treatment, biocontrol agents, integration

INTRODUCTION

A prompt selection and implementation of viable alternatives to methyl bromide (MB) in Central and Eastern European countries is very important for meeting its 2005 phase out requirement. To assist the countries in the region in identifying MB alternatives, UNEP has launched a regional demonstration project in Poland to evaluate the range of chemical and non-chemical alternatives on horticultural crops. Poland has the highest level of MB consumption among the Central and Eastern European countries. In these countries, MB is predominantly used on horticultural crops such as peppers, tomatoes, cucumbers, strawberries and some ornamental plants.

Effective control of the soil-borne strawberry disease complex is a precondition to obtain pest-free propagation material. The direct control of Verticillium wilt is a one of special importance. Until now, sufficiently resistant cultivars have not been available commercially (Shaw & Larson 2001). Germplasm was not found containing obvious genetic diversity that would be useful for developing cultivars specifically adapted to the sublethal effects of organisms in nonfumigated soils (Fort *et al.* 1996; Shaw & Larson 1996). Strawberry productivity can be substantially reduced by growing plants in soil that has not been fumigated prior to planting, even in the absence of lethal pathogens (Chandler *et al.* 2001; Hancock *et al.* 2001).

MATERIALS AND METHODS

Three demonstration experiments were conducted on commercial strawberry farms during 2000 and 2001.

The first experimental site was located at Kielczewo (central western Poland) with the cultivar Camarosa. Each chemical treatment was applied in strips of 2.5 m wide and 250 m long. The transplants were planted on April 20 each year. The soil fumigation was done in the beginning of November 1999 and in mid-October 2000. MB and 1,3-D+CP were applied by an injection method using a tractor injector together with a simultaneous covering of the soil with a double layer of PE film. Dazomet and metam sodium were sprayed on soil, mixed with a rototiller and the soil was compacted with a roller. The following chemicals were applied in 2000: A. MB (Metabrom 98) - 600 kg/ha; B. Dazomet (Basamid GR®) - 500 kg/ha; C. 1,3-D+CP (Telopic®) - 380 l/ha; D. 1,3-D+CP - 530 l/ha; E. Metam sodium (Nemasol®) - 800 l/ha; F. Metam sodium - 1,200 l/ha; G. Control. In year 2001 the following soil treatments were included: A. MB - 600 kg/ha; B. 1,3-D+CP - 375 l/ha; C. Control. In the treatments B, C, E and G in 2000 and in all the treatments in 2001, 1/3 of the transplants used for each band were also dipped in a suspension of *T. viride* B35 or *P. fluorescens* PSR21. The suspension of *T. viride* (10^9 c.f.u./ml) was made in water with starch (40 g/l). The suspension of *P. fluorescens* (10^9 c.f.u./ml) was prepared in a solution of 0.1 M $MgSO_4$ and 0.1% of CMC.

The second experimental site was located at Przysieka (central Poland) with cultivar Tudnew. Each chemical treatment, integrated or not with biocontrol agents, was set up on plots 4.6 m wide (4 rows) and 45 m long. The transplants were planted on 20April 2001. The applications of fungicides and biocontrol agents were done similarly as it was described in experiments at Kielczewo. The soil fumigations were done in October 2000 with the following treatments: A. MB - 600 kg/ha; B. Metam sodium - 1,000 l/ha; C. Metam sodium - 1,200 l/ha; D. Metam sodium - 1,500 l/ha. In the treatments with metam sodium, the transplants were also dipped in the suspension of biocontrol agents.

The third experiment was set up in the southern part of Poland in 2000 with the cultivar Senga Sengana. Soil and transplant treatments were done similarly as at Kielczewo. The transplants were planted on 18May 2000. The fumigation was done in November 1999 except for metam sodium which was applied at the end of March 2000. Only the 1,3-D+CP was applied at different doses (500 and 700 l/ha).

The laboratory evaluation of the effectiveness of the tested alternatives was carried out. For these purposes, the presence of the phytopathogenic fungi on roots was evaluated by a plate count. The surface was disinfected with acidified chloramin. T 100 root fragments (~0,5 cm long) were placed on a selective agar media for isolation of *Fusarium* (Burgess et al. 1988), *Phytophthora* (Jeffers & Martin 1986) and *Verticillium* (Jordan 1971).

RESULTS AND DISSCUSSION

The first assessment of weed control by the chemical treatment was performed at planting time at all locations. In both years the bands treated with MB in all locations as well as the band with dazomet in 2000 were apparently free from primary weed infestation. At Kielczewo in the bands treated with 1,3-D+CP in the both years and with a lower dose of metam sodium in 2000, the percentage of ground covered by weeds was only slightly lower than that in the control bands. At this location, the higher dose of metam sodium (1,200 l/ha) reduced the weed infestation by about 50% in 2000. The dominant weed species were *Arthemidae, Echinochloa crus-gall, Erodium cicutarium* and *Viola tricolor*. The weed infestation of untreated bands and the ranking order of the chemicals in controlling weeds at Brzezna was similar as at Kielczewo in 2000.

In the second year after the fumigation at Brzezna, practically no effect of the soil fumigants on weeds was observed. The dominant weed species were *Cirsium* spp., *E. crus-gall, Galinsoga parviflora* and *Agropyron repens.* In the experiment at Przysieka the herbicidal effectiveness of Nemasol at all three doses evaluated one week prior to planting was very low and the reduction of the weed infestation did not exceed 30%. The dominant weed species were *Arthemidae, E. crus-gall, E. cicutarium* and *V. tricolor*. The second assessment of the weed infestation done at the end of July in both years revealed that commercially acceptable weed control was achieved only in bands treated with MB in all locations.

In the experiment at Brzezna in 2000, the vigour of the plants in untreated bands at the early growing period was visibly poorer than in the MB, 1,3-D+CP and metam sodium (1,200 l/ha) treated bands (Table 1). The stimulating effect of MB and 1,3-D+CP soil treatments was even more pronounced at Kielczewo in 2001. However, the effect of 1,3-D+CP was significantly lower than the effect of MB (Table 1). In most cases, both biocontrol agents applied as a transplant drench treatment stimulated noticeably the development of the mother plants in comparison with the chemicals applied alone at Brzezna (Table 1).

TABLE 1: The effect of MeBr and alternatives on plant vigour in field conditions expressed by the area of plant (cm^2).

Soil treatment	Transplant treatment		
	Control	T. viride	*P. fluorescens*
Experimental site, Kielczewo 4 July 2001, cv. Camarosa			
Control	805 c*	822 c	699 c
1,3-D+CP 375 l/ha	1,149 b	1,148 b	1,149
Methyl bromide 600 kg/ha	1,360 a	1,356 a	1,388
Experimental site, Brzezna 28 September 2000, cv. Senga Sengana			
Control	4,822 b	4,768 b	5,366
Dazomet 500 kg/ha	4,755 b	4,754 b	5,005
1,3-D+CP 500 l/ha	5,634 a	5,400 ab	5,480
1,3-D+CP 700 l/ha	5,285 ab	4,836 b	4,836
Metham sodium 800 l/ha	4,882 b	4,913 b	4,955
Metham sodium 1,200 l/ha	5,061 ab	5,269 ab	5,310
Methyl bromide 600 kg/ha	5,434 ab	5,356 ab	5,699

** Values followed by the same letters within the frame of the same experimental site are not significantly different within the columns according to Newman-Kuels test (α < 0,05),*

At Przysieka, the vigour of the plants in the bands treated with Nemasol during the early growing period was substantially poorer than that of the MB-treated soil (data not shown).

The phytopathological studies of strawberry plant root infestation revealed a lack of root infestation with *Phytophthora* and *Fusarium* at Brzezna in 2000. We have isolated sporadically fungal colonies (< 4%) on selective media for *Verticillium* from untreated bands. Sampled roots from Kielczewo in 2000 were infested with *Phytophthora* in the range from 44% to 11% in the control and in the MB treated bands, respectively. Several isolates were identified as *P. cactorum*. The plants affected by this pathogen were randomly scattered all over the field. The chemical treatments alone and in the combination with the biocontrol agents significantly reduced (about 50%) the spread of this pathogen in comparison with untreated bands.

In 2001 on selective *Fusarium* medium, single colonies (< 7%) were detected from roots sampled at Kielczewo. No symptoms of *Phytophthora* were visible during the vegetation period and no isolates on the root segments were found. The enumeration of *Verticillium* showed that the significant number of root segments (41–50%) sampled from the untreated bands was colonised by this pathogen in 2001. Most of the selected isolates were identified as *V. dahliae* but the characteristic visible disease symptoms were not observed in the field. The great number of root segments (45-47%) sampled from the Nemasol-treated bands at Przysieka were infected by *Verticillim* and this observation could be connected with observed severe symptoms of Verticillium wilt (Table 2). Most of the selected isolates were identified as *V. dahliae*. Moreover, a few cultures isolated on selective media revealed also the presence of *F. culmorum* and *F. oxysporum*.

TABLE 2: The Verticillium wilt incidence at Przysieka expressed as percentage of wilted plants.

Soil treatment	Transplant treatment		
	Control	T. viride	*P. fluorescens*
Metham sodium 1,000 l/ha	16.3	5.6	14.4
Metham sodium 1,200 l/ha	12.8	8.8	4.1
Metham sodium 1,500 l/ha	1.6	8.8	3.1
Methyl bromide 600 kg/ha	0.7	N.D.	N.D.

TABLE 3: The effect of MB and alternatives on the productivity of runners.

Soil treatment	Transplant treatment		
	Control	**T. viride**	***P. fluorescens***
Experimental site, Kielczewo 2000, cv. Camarosa			
Control	26	25	26
Dazomet 500 kg/ha	30	35	33
1,3-D+CP 380 l/ha	26	34	31
1,3-D+CP 530 l/ha	33	ND	ND
Metham sodium 800 l/ha	22	28	27
Metham sodium 1,200 l/ha	33	ND	ND
Methyl bromide 600 kg/ha	49	ND	ND
Experimental site, Kielczewo 2001, cv. Camarosa			
Control	48	64	40
1,3-D+CP 375 l/ha	61	64	65
Methyl bromide 600 kg/ha	53	84	74
Experimental site, Przysieka 2001, cv. Tudnew			
Metham sodium 1,000 l/ha	54	71	62
Metham sodium 1,200 l/ha	71	58	59
Metham sodium 1,500 l/ha	64	66	69
Methyl bromide 600 kg/ha	72	ND	ND

Table 3 shows that MB and 1,3-D+CD had a positive influence on the mother strawberry plants productivity. In addition, the treatment of transplants with the biocontrol agents planted in the bands fumigated with MB resulted in a well-pronounced improvement of the productivity. Moreover, the treatment of transplants with *T. viride* alone increased the productivity of transplants in the control plots. Sivan & Chet (1993) described similar synergistic effect in a experiments with controlling the crown and root rot of tomato.

The data obtained indicate that, in the production of strawberry transplants, 1,3-D+CP alone or at a lower dosage integrated with a biocontrol agent *T. viride* B35 could be considered as possible replacements for MB with regard to the control of soil-borne pathogens, but not as a weed control agents.

The effectiveness of 1,3-D+CP in controlling soil-borne pathogens in our trails was similar to that described by Larson & Shaw (2000) as well as Rieger *et al.* (2001). The results of runners' production and the mycological studies indicate that Nemasol controlled the Verticillium wilt at higher doses but the effectiveness was not acceptable for commercial reasons (Table 3). The additional transplant treatments with biological agents did not significantly improve the effectiveness of Nemasol. In strawberry production, Nemasol could not be considered as an alternative equivalent to MB. Others reported similar results in the production of tomato (Locascio *et al.* 1997) and in the first year production of strawberry (Riegier *et al.* 2001).

The yield of fruit collected during 2001 showed that 1,3-D+CP in lower dose gave a similar effect as the MB treatments (Table 4). All the other chemical treatments did not influence the yield of strawberries. In addition, a significant stimulating effect was observed on virtually all plots treated with *Trichoderma* (except for the higher dose of 1,3-D+CP) in comparison with the corresponding plots treated with fumigants alone. The assessments of the yield confirmed the results from the previous year when plant vigour had been estimated which was the performance of 1,3-D+CP applied alone or in combination with both tested biocontrol agents was very good and very similar to MB. Moreover, the results of combining *T. viride* and dazomet showed a similar effect to MB combined with this biocontrol agent in terms of fruit production. The results of the plant performance and the mycological analyses suggest that some minor pathogens may also have influenced the strawberry growth in Brzezna.

In these experiments, the performance of all the evaluated alternatives was inferior to the consistent, broad-spectrum control provide by MB, as reported previously (Locascio *et al.* 1997; Larson & Shaw 2000). However, taking into account the improvements of plant vigour and their higher productivity, the use of 1,3-D+CP at a higher rates and the combination of *T. viride* B35 with reduced dosage of 1,3-D+CP (375 l/ha) suggests a possible replacement for MB in the production of strawberry.

Table 4: The effects of MB and alternatives on the fruit production of strawberry cv. Senga Sengana (t/ha).

Soil treatment	Transplant treatment		
	Control	T. viride	*P. fluorescens*
Control	16.4	19.4	17.9
Dazomet 500 kg/ha	13.3	20.9	18.5
1,3-D+CP 500 l/ha	19.3	19.2	18.1
1,3-D+CP 700 l/ha	17.0	14.0	20.4
Metam sodium 800 l/ha	14.4	20.5	11.7
Metam sodium 1,200 l/ha	14.7	19.3	17.3
Methyl bromide 600 kg/ha	19.4	21.1	19.8

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CARBONYL SULFIDE AND CYANOGEN AS POTENTIAL NEW SOIL FUMIGANTS

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ABSTRACT

Penetration of carbonyl sulfide (COS) and cyanogen (C_2N_2) through soil, and sorption or uptake of the fumigants by soil, was tested on a variety of soil types from New South Wales (NSW) and Western Australia (WA). Both COS and C_2N_2 diffused and penetrated through the soils faster and deeper than methyl bromide (MB) and carbon disulfide. Soils of different moisture content were fumigated in sealed gas jars. Sorption of the fumigants was measured by monitoring the loss of the fumigants in the headspace. Cyanogen was rapidly and strongly sorbed by all soils, followed by COS and MB. That is, cyanogen and COS were partitioned with higher ratio into soils than MB, which means that there is less emission to air. Both fumigants were stable in soil for 3-5 hr, after which they were broken down to naturally occurring soil components, such as H_2S and CO_2. Both COS and C_2N_2 were shown to control 1st-instar whitefringed weevil, *Graphognathus leucoloma* (Boheman), nematodes (*Steinernema carpocapsae*) and soil pathogens (*Fusarium graminearum, Bipolaris soroikiniana, Pythium irregulare and Rhizoctonia solani*).

Keywords: methyl bromide, alternatives, carbonyl sulfide, and cyanogen, whitefringed weevil, soil pathogens, nematodes

INTRODUCTION

More than 80% total fumigant of methyl bromide (MB) is used for soil fumigation. Given the limited existing alternatives for soil fumigation, it is important to develop new materials for this application that meet the requirements of being highly toxic to soil insects, mites, nematodes, and pathogens, easy and safe to apply and minimally deleterious to the environment.

CSIRO Entomology, Stored Grain Research Laboratory (SGRL) has developed and patented two new fumigants (Banks *et al.* 1992; Desmarchelier and Ren 1996), carbonyl sulfide (COS) and cyanogen (C_2N_2) to replace methyl bromide (MB) in a variety of applications. Carbonyl sulfide is currently being commercialised for use on grain. Cyanogen appears to have particularly good potential for timber. However, soil fumigation is one of the largest uses of MB that will be phased out under the terms of the Montreal Protocol. This preliminary work is aimed at assessing the potential of COS and C_2N_2 for use as soil fumigants.

MATERIALS AND METHODS

Penetration of COS and C_2N_2 through soil

The procedure for studying sorption was first to condition the soil to 27% (gingin sand) and 52% (pemberton loam), as determined by oven drying method. Second, the soil sample, loosely packed, was weighted and then transferred (with 95% full) to a 700 mL PVC column (7 cm $\phi \times$ 18 cm h) equipped with sampling ports on the wall of column. Fumigant (60 mg/L) was injected at bottom of column. The fumigant concentrations at different levels were measured by gas chromatography (GC).

Laboratory bioassays on insects, nematodes and fungi

Tests were conducted in 200 ml glass bottles equipped with an airtight cap that allowed gas injection through a septum. The insect cage (containing about 50-60 whitefringed beetle larvae) was placed into the bottle and then covered with soil (30% full). Fumigants were injected into separate bottles with airtight syringe. Controls were sets of 50 larvae in sealed bottles containing the soil sample.

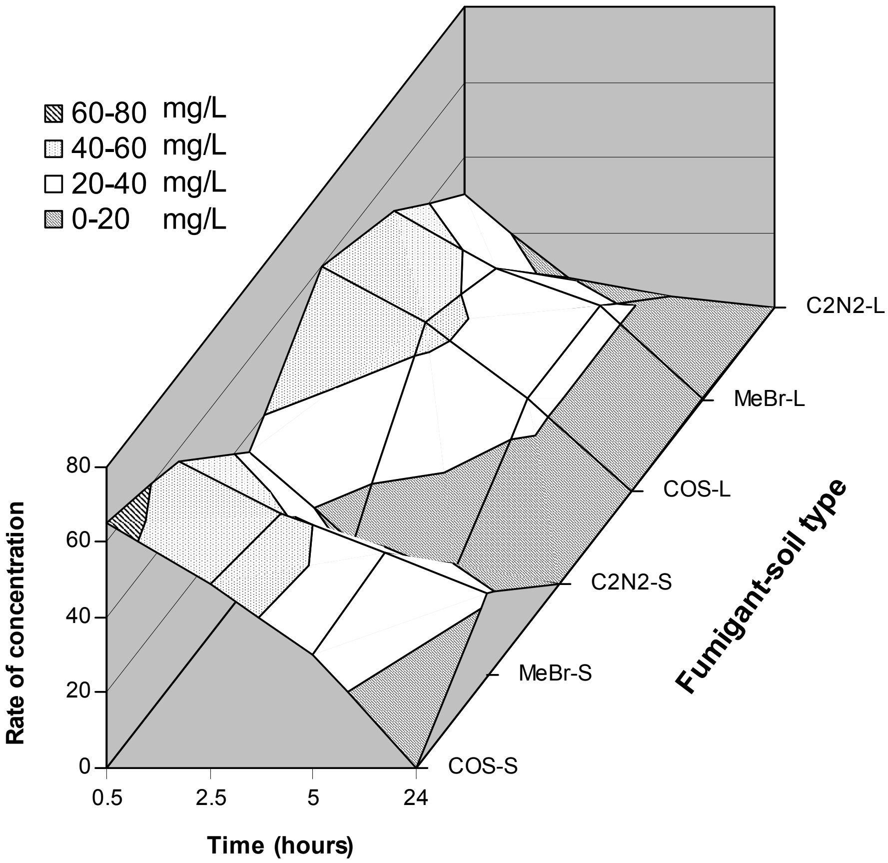
The flasks (275 ml) were sterilised and the bottom centimetre filled with a growth medium (potato dextrose Agar). The centre of the flask was inoculated with a pathogen. The flasks were then sealed. Each of the above operations was performed in a laminar-flow cabinet. The sealed flasks were then placed in a room at 25°C. The pathogens were allowed to grow until they had attained a colony diameter of approximately 30 mm. Fumigant was then injected through the septum. The colony diameter was measured, in both control and treated pathogens, after a holding period of 24 hours. After 24 hours, the control pathogen had not grown to the edge of the flask (<800 mm). The growth of the pathogen in treatments could then be calculated as a proportion of that in the control.

RESULTS AND DISSCUSSION

Penetration of COS and C_2N_2 through soil

Both COS and C_2N_2 diffused and penetrated through the soils faster and deeper than MB and CS_2 (Figure 1).

FIGURE 1: Penetration of COS and C_2N_2 through soil and sorption or uptake of the fumigants by a variety of soil types (S-gingin sand and L-pemberton loam).



Cyanogen was rapidly and strongly sorbed by all soils, followed by COS and MB. That is, C_2N_2 and COS were partitioned with higher ratio into soils than MB, which means that there is less emission to air. Both fumigants were stable in soil for 3-5 hr, after which they were broken down to naturally occurring soil components, such as H_2S and CO_2.

Laboratory bioassays on insects, nematodes and fungi

TABLE 1: Toxic to 1st-instar whitefringed weevil (Larvae) *Graphognathus leucoloma* (Boheman), at 25±2C°, with soil (30% fill) and 5 hours exposure.

L(CXt) mg h/L	C_2N_2	COS	MB
L(CXt)50	30	300	100
L(CXt)95	50	370	135

TABLE 2: Toxic to nematodes (*Steinernema carpocapsae*) at 25±2C°, with soil (30% fill) and 5 hours exposure.

L(CXt) mg h/L	**C_2N_2**	**COS**	**MB**
L(CXt)50	25	110	75
L(CXt)95	40	210	100

TABLE 3: Toxic to soil pathogens at 25±2C° and 24 hours exposure.

Pathogen	**Fumigant (mg/L)**		
	C_2N_2	**COS**	**MB**
F. graminearum	4	200	80
B. soroikiniana	6	250	65
P. irregulare	4	170	45
R. solani	8	150	55

Assessment of total environmental impact

Neither COS nor C_2N_2 are listed as greenhouse gases. The threshold limit values (TLV) for COS and C_2N_2 of 10 ppm (v/v) compares favourably with both MB (5 ppm) and phosphine (0.3 ppm). They are naturally-occurring gases present at low concentrations in the atmosphere, soil, ocean, vegetation and grain.

The average total worldwide release of COS was at about 3 million tonnes/year of which less than one third was related to human activity (HSDB 1994). Recent investigations have shown that COS plays an important role in the chemistry of the global atmosphere and in the biogeochemical sulfur cycle (Sze and Ko 1980; Gregory *et al.* 1993; Ren 1999). One of the major sinks for COS is direct removal from the atmosphere by plants and soil microorganisms (Bremner and Banwart 1976; Brown *et al.* 1986). The atmospheric half-life for carbonyl sulfide is at about 2 years (HSDB 1994). The most important fate process for carbonyl sulfide in water is volatilisation where the half-life is about 2.3 hours (HSDB 1994).

The chemistry of C_2N_2 is also well understood. It is a colourless gas with a boiling point of -21.2°C. It has an almond-like odour, which becomes acrid and pungent at high concentrations, making it detectable to the user should a leak occur. Unlike most fumigants, C_2N_2 is readily soluble in water, with 1 volume of water dissolving 4 volumes of C_2N_2. In aqueous solutions it is slowly hydrolysed to form oxalic acid and ammonia. At low pH, C_2N_2 reacts to form derivatives of formic acid and hydrogen cyanide (HCN). Hydrogen cyanide is found in nature in some vegetable substances, e.g., bitter almond, peach stones, cherry and sorghum; it is usually combined in glycoside molecules and is released when they are broken down by enzymes during metabolism.

Guideline Maximum soil concentrations for HCN residential soil is 250 mg/kg free HCN, 500 mg/kg complexed. For commercial or industrial soil 1250 mg/kg free HCN, 2500 mg/kg complexed (NEPM, 1999). However, the data from laboratory studies showed 150 mg/kg of C_2N_2 can control all target organisms (include insect and nematodes <80 mg/kg; soil borne pathogens and soil fungi <120 mg/kg). In the case of 100% applied C_2N_2 (150 mg/kg) converts to HCN. The levels of HCN residue are about 78 mg/kg, which are much lower than that maximum soil concentration. Cyanogen can be directly/indirectly utilised by plants or organisms.

CONCLUSIONS

Carbonyl sulfide and C_2N_2 appear to have potential as soil fumigants to replace MB. Formulations and application methods are being investigated to develop good agricultural practice for these fumigants.

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FURFURAL-BASED BIOFUMIGANT MIXTURES FOR CONTROL OF PHYTOPATHOGENIC NEMATODES AND WEEDS

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ABSTRACT

The nematicidal and herbicidal activities of furfural (2-furfuraldehyde), and mixtures of furfural and mustard oils and naturally occurring isothiocyanates, were studied in greenhouse and microplot experiments with soils naturally-infested with a variety of plant parasitic nematodes and weeds. Nematode species present included root-knot nematodes (*Meloidogyne arenaria* and *M. incognita*), the reniform nematode (*Rotylenchulus reniformis*) and the lesion nematode (*Pratylenchus brachyurus*). Weed species were: nutgrasses (*Cyperus esculentum* and *C. rotundus*), crab grass (*Digitaria sanguinalis*), Jimson weed (*Datura stramonium*) and a variety of other weed species. Data from these experiments indicate that a variety of effective broad-spectrum formulations of furfural can be developed for the control of economically important soil-borne pests. Furfural-based biofumigants were very effective against phytopathogenic nematodes but had no deleterious effects against beneficial microbivorous nematodes. The biofumigants have herbicidal activities at commercially feasible rates against most common weeds but must be applied at high rates (> 500 kg ai/ha) to control nutgrass-type weeds.

Keywords: biofumigants, 2-furfuraldehyde, herbicide, horticultural crops, isothiocyanates, microbivorous nematicides, nematodes, mustard oils, nematicide, plant parasitic nematodes, root-knot nematodes, soil fumigation, weed control.

INTRODUCTION

There are a number of plant species that have relatively few problems caused by soil-borne pests. Some of these plants, e.g. brassicas, mustards, radishes, have been used as rotational crops to suppress nematodes and soil-borne fungal pathogens. Cruciferous plants produce a variety of mustard oils some of which are very active against plant pests. Other plant species, e.g. oregano, thyme, lemon grass, produce simple volatile monoterpenes, terpenoids and aromatic compounds with considerable activity against phytopathogenic fungi, nematodes and other soil-borne plant pests (Harborne & Baxter 1993; Grainge & Ahmed 1988).

Research on the nematicidal and microbiocidal properties of these volatile, naturally occurring compounds has shown promise for development of new management strategies for nematodes and other soilborne plant pathogens (Soler-Serratosa 1993;Soler-Serratosa *et al.* 1996). Furfuraldehyde, a product obtained from sugarcane bagasse and similar biomass materials (Merck Index 1989), alone, and in combination with mustard oils, for example, was shown to be effective for the management of weeds, insects, nematodes and other soilborne pathogens (Rodríguez-Kábana 2000; Rodríguez-Kábana *et al.* 1993; Rodríguez-Kábana & Walters 1992).

In contrast to MB and other similar “broad-spectrum” soil fumigants (biocides), natural fumigants are directly active against target pests, while favoring or stimulating select groups of beneficial microbial species in soil (Canullo *et al.*1992; Chavarria-Carvajal & Rodriguez-Kabana 1992; Soler Serratosa *et al.,* 1994). Many of the selected microorganisms are antagonistic to phytopathogenic nematodes and fungi, e.g., species of root-knot (*Meloidogyne*) and cyst (*Heterodera*) nematodes, the reniform nematode (*Rotylenchulus reniformis*), fungi such as: *Rhizoctonia solani*, *Fusarium* spp., *Verticillium* spp, and bacteria. The mode of action of these natural fumigants (selector compounds) involves short-term direct action against target pests and long-term activity through selection of beneficial microorganisms antagonistic to the pests.

Prolonged use of mixtures of selector compounds can enhance suppressiveness of soils against pests through enrichment of the soil microflora with species antagonistic to the pests. In essence, applications of these mixtures can result in benefits typical of those obtained with pest-suppressive crop rotations without the need to dedicate the land and time necessary to implement these rotations. These possibilities led the Nematology team at Auburn University to explore the use of furfural-based biofumigants as alternatives to methyl bromide (MB) for the control of weeds, nematodes and other soil-borne pests.

MATERIALS AND METHODS

Greenhouse Experiments. The nematicidal activity of an emulsifiable formulation of furfural (2-furfuraldehyde; Illovo Sugar Ltd., Durban, South Africa) was studied in a greenhouse experiment with a soil naturally infested with the reniform nematode (*Rotylenchulus reniformis*). A 5% (v/v) aqueous emulsion of the chemical was added to one kg amounts of soil to deliver furfural rates of: 50, 100, 200, 300, 400 and 500 uL/kg soil. The treated soil was mixed well and transferred to IL capacity 10-cm-diam cylindrical plastic pot. Untreated soil (control) and each rate of the chemical were represented in the experiment by 14 pots (replications), one-half of which were covered with a plastic bag held down with a rubber band around the pots while the other 7 were left uncovered. The pots were placed on a greenhouse bench and soil samples for nematological analysis (salad bowl incubation technique) were collected two weeks after application of the material.

In another greenhouse experiment of identical design, an aqueous emulsion containing 17% furfural was added at rates of 170 - 1700 uL ai/kg soil to a soil infested with crab grass (*Digitaria sanguinalis*), purple nutsedge (*Cyperus rotundus*), Jimson weed (*Datura stramonium*) and a variety of other weed species. In other experiments of similar design as those described, mixtures of furfural with small amounts (<20%) of mustard oil or various naturally occurring isothiocyanates were applied to nematode and weed infested soil at rates of 50 - 1700 uL ai/kg soil. Variables studied in the experiments were weed and nematode numbers.

Microplot Experiment. A microplot trial was conducted on the Auburn University's campus microplot facilities to determine the efficacy of a Multiguard FFA^{TM} formulation (Harborchem, Cranford, New Jersey) as a MB alternative. The emulsifiable formulation consisted of a mixture of furfural containing 25% allyl isothiocyanate. The chemical material was applied to soil by drenching-in an aqueous emulsion in sufficient quantity to penetrate 40 cms into the soil profile. A microplot consisted of a one-ft^2 (929 cm^2) area delimited by a *terra cotta* chimney liner (2.54 cm- thick wall) embedded 41 cms deep into the soil and protruding 2 cms above the soil. Soil in the microplots was a loamy sand with pH= 6.2, organic matter content <1.0%, and cation exchange capacity < 10 meq/100 g soil. The soil was typical for Alabama and was infested with a variety of plant parasitic nematodes including root-knot nematodes (*M. arenaria, M. incognita,* and species of *Helicotylenchus, Hoplolaimus, Paratrichodorus, and Pratylenchus*), southern blight (*S. rolfsii*), and typical damping off (*Rhizoctonia, Pythium*) and wilt (*Fusarium, Neocosmospora*) pathogens. The microplots were infested with nutsedge (*Cyperus esculentum* & *C. rotundus*) and other weeds which, in combination with the other pests present in the soil, represented closely the problems faced by producers in fields requiring fumigation with MB.

Multiguard FFA was applied at rates in the range of 0, 2.5, 5.0, 10, 15, 20, 25 and 37/5 g ai/plot (1.0 g ai/plot is approximately equivalent to 100 kg ai/ha.). The treated soil was covered with standard polyethylene plastic for 3 weeks, after which the the cover was removed, the weeds were counted and soil samples were collected for nematological analyses. Treatments in the trial were arranged in a randomized complete block design and each treatment was represented by 8 replications (plots).

Statistical Analyses. Data from the experiments were analyzed by standard procedures for analyses of variance. When F values were significant ($p \leq 0.01$) differences among means were evaluated for significance according to Duncan's multiple range test. Unless otherwise indicated differences referred to in the text were significant at $p \leq 0.01$.

RESULTS

Greenhouse Experiments. Numbers of the reniform nematode in soil declined sharply in direct response to increasing rates of furfural with the sharpest reductions in numbers occurring at rates $\leq$ 200 uL/kg soil. There were no nematodes in samples from covered pots that received furfural at rates $\geq$ 200 uL/kg soil. The reniform nematode was not eliminated in any of the samples from uncovered pots.

In the experiment with weeds, application of furfural to covered pots at rates ≥680 uL/kg soil eliminated all weeds 14 days after treatment but in the uncovered pots only the two highest rates resulted in consistent and adequate control (>70%) of most weeds. Data from experiments using mixtures of furfural mustard oil or naturally occurring isothiocyanates indicated that application of these mixtures to soil resulted in superior nematicidal and herbicidal activities than were obtained from furfural alone or the other active ingredients in the mixtures.

Microplot Experiment. Application of Multiguard FFA at 2.5 g ai/plot eliminated or drastically reduced populations of plant parasitic nematodes in soil (Figure 1A). This was in direct contrast to the pattern of response obtained for microbivorous (benefitial) nematode populations; numbers of these nematodes were either unaffected or greatly stimulated by applications of Multiguard FFA (Figure 1B).

Most weed species were controlled by Multiguard FFA at rates 5 – 10 g ai/plot. However, nutgrass control required applications ≥ 15 g ai/plot to obtain satisfactory control of these weed species.

CONCLUSIONS

Data from these experiments indicate that a variety of effective broad-spectrum formulations of furfural can be developed for control of economically important soil-borne pests. Results also indicate that furfural-based biofumigants, while very active against phytopathogenic nematodes, have no deleterious effects against beneficial microbivorous nematodes. These biofumigants have herbicidal activities against most common weeds but must be applied at high rates (> 500 kg ai/ha) to kill nutgrass-type weeds.

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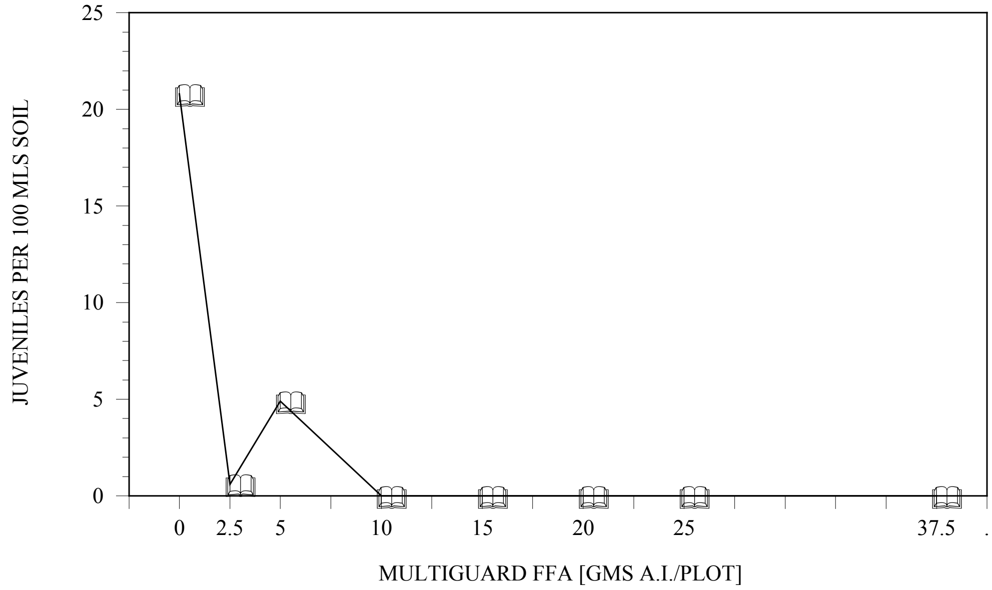

Figure 1A. Effect of applications of Multiguard FFA (Furfural + Allyl Isothiocyanate) on populations of root-knot nematode (*Meloidogyne* spp.) in a microplot experiment at Auburn University (1.0 g/plot is approximately equivalent to 100 kg/ha)

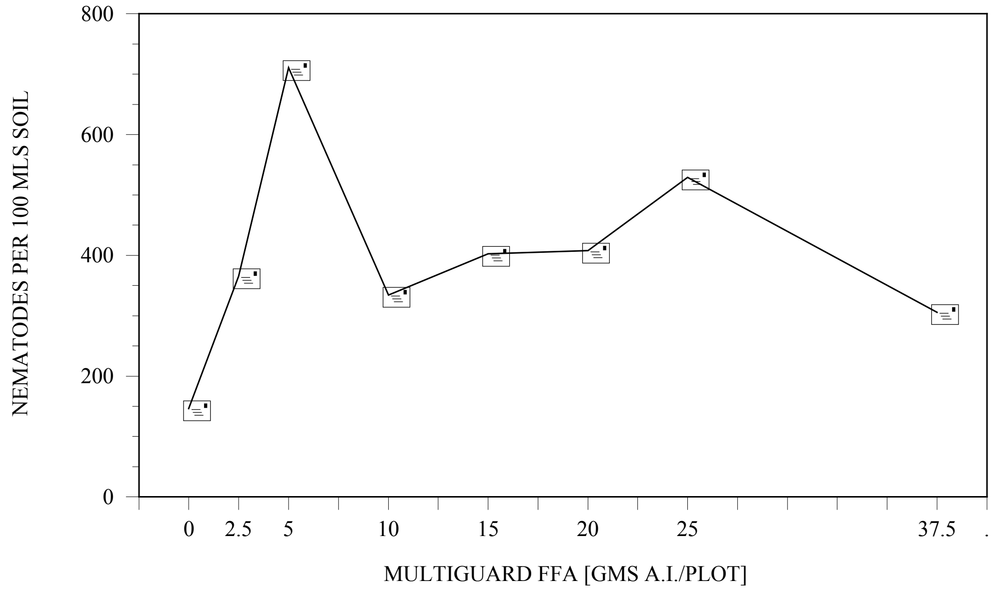

Figure 1B: Effect of applications of Multiguard FFA (Furfural + Allyl Isothiocyanate) on populations of beneficial microbivorous nematodes in a microplot experiment at Auburn University.

POTENTIAL OF PROPYLENE OXIDE AS A SUBSTITUTE FOR FUMIGATION OF SOIL WITH METHYL BROMIDE

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ABSTRACT

The nematotoxic properties of propylene oxide (CH_2O CH CH_3) were studied in greenhouse and microplot experiments. In greenhouse experiments with soil from a cotton field infested with the phytopathogenic reniform nematode (*Rotylenchulus reniformis*), numbers of the reniform and beneficial microbivorous nematodes in pre-plant soil samples, taken two weeks after treatement of the soil, declined sharply in response to increasing propylene oxide (PO) rates up to 750 mg/kg soil; dosages $\geq$750 mg/kg soil resulted in 100% kill. The same pattern of response to PO applications was observed for soil and root populations of *R. reniformis* at termination of the experiment 8 weeks after planting of 'Young' soybean (*Glycine max*). Significant populations of microbivorous nematodes were observed in control and all PO-treated soils at the end of the experiment; soil and root populations of these nematodes increased directly in response to PO dosages between 125-1000 mg/kg soil but declined in soils treated with rates $\geq$1125 mg. Weights of fresh roots and shoots were increased by all PO rates but the highest increase for the two variables was observed in response to the lowest PO dosage (125 mg/kg soil). In other greenhouse trials, application of a 5% aqueous PO solution to a soil infested with crabgrass (*Digitaria sanguinalis*), yellow nutsedge (*Cyperus esculentum*), Jimson weed (*Datura stramonium*) and a variety of other weed species resulted in 100% control of all weeds at rates >600-800 mg ai/kg soil. Results from a microplot experiment demonstrated that PO injected directly into soil to a depth of 36 cms was effective in controlling phytopathogenic nematodes, yellow nutsedge and other weeds at rates of $\geq$ 12 ml/m row (approx. 231 - 278 L/ha, depending on bed or row width). Drenching soil with a 20% aqueous solution of PO was 40-50% less effective than direct injection of the chemical for control of weeds in the microplots.. Data from these experiments, considered with current price, commercial availability, and relatively low mammalian toxicity, indicate that PO has great potential for development as an alternative to methyl bromide for fumigation of soils.

Keywords: herbicide, horticultural crops, propylene oxide, methyl bromide, microbivorous nematicides, nematodes, nematicide, plant parasitic nematodes, soil fumigation, weed control.

INTRODUCTION

Propylene oxide (PO) is a flammable, colorless ethereal liquid, soluble in water (40.5% by weight, 20^0C), miscible with alcohol, ether and other like solvents, with LD_{50} = 1.14 g/kg administered orally to rats (Merck 1989; Smyth *et al.* 1941). It is used as an intermediate in the preparation of polyethers to form polyurethanes, in the synthesis of propylene glycols, lubricants, surfactants and demulsifiers. PO, like gaseous ethylene oxide (CH_2O CH_3), has been used for laboratory and small scale fumigation of soils and other materials, such as food stuffs, microbiological nutrient media (Dhingra & Sinclair 1985; Klarman & Craig 1960; Hansen & Snyder 1947; Smyth *et al.* 1941; Tuite 1969; Thompson & Gerdemann 1962; Warren 2001; Watson *et al.* 1966).

In contrast with ethylene oxide, the liquid nature of PO at ordinary atmospheric pressure and temperatures, simplifies its use as a fumigant. These and other practical considerations led Nematology Research at Auburn University to study the feasibility of using PO as a substitute for methyl bromide (MB) as a soil fumigant. A preliminary report on results from this effort has been presented (Rodriguez-Kabana 2001).

MATERIALS AND METHODS

Greenhouse Experiments. The nematotoxic properties of an aqueous solution (2.5%, v/v) of PO (Aldrich, Milwaukee, WI 53201, U.S.A.) were studied in a greenhouse pot experiment with soil from a cotton field infested with the reniform nematode (*Rotylenchulus reniformis*). The soil was sandy loam with pH 6.2, organic matter content $\leq$1.0% and cation exchange capacity

≤ 10 meq/100 g soil. PO was added pre-plant to the soil at rates of 125 - 1500 mg/kg soil in increments of 125 mg. The treated soil was mixed well and transferred to one liter capacity 10-cm-diam cylindrical plastic pots. The pots were then covered with standard transparent polyethylene (1ml) tarp. Each experiment contained a control and 12 treatments each with 7 replications (pots) arranged in a randomized complete block design. After two weeks, the covers were removed, soil samples for nematological analyses (salad bowl incubation technique) were collected and 'Young' soybean planted (5 seed/pot). In other greenhouse trials, a 5% aqueous PO solution was applied to soil infested with crabgrass (*Digitaria sanguinalis*), yellow nutsedge (*Cyperus esculentum*), Jimson weed (*Datura stramonium*) and a variety of other weed species. Experimental design and procedure for these experiments were as described for the experiment on nematicidal activity.

Microplot Experiment. A microplot trial was conducted at the Auburn University's campus microplot facilities to compare the relative efficacy of PO applied as a drench in an aqueous solution of the chemical and application of the undiluted PO by direct injection into the soil. A microplot consisted of a one-ft^2 (929 cm^2) area delimited by a *terra cotta* chimney liner (2.54 cm- thick wall) embedded 41 cms deep into the soil and protruding 2 cms above the soil. Soil in the microplots was a loamy sand with identical properties to the soil used for the greenhouse experiments. The soil was typical for Alabama and was infested with a variety of plant parasitic nematodes including root-knot nematodes (*M. arenaria, M. incognita,* and species of *Helicotylenchus, Hoplolaimus, Paratrichodorus, and Pratylenchus*), southern blight (*S. rolfsii*), and typical damping off (*Rhizoctonia, Pythium*) and wilt (*Fusarium, Neocosmospora*) pathogens. The microplots were infested with nutsedge (*Cyperus esculentum* & *C. rotundus*) and other weeds which in combination with the other pests present in the soil represented closely the problems faced by producers in fields requiring fumigation with MB. In the drenching application, PO was added to the microplot as a 20% (v/v) PO aqueous solution by mixing the required amount of the solution in sufficient water (final volume = 2L/microplot) to penetrate 40 cms into the soil profile. Direct injection of PO was to a depth of 36 cms in a 5-cm-wide trench dug along a diagonal line in the square microplot; after application the soil on both sides of the trench was pushed in to cover the trench. The untreated (control) and treated microplots were covered with standard polyethylene plastic for 3 weeks, after which the the cover was removed, the weeds were counted and soil samples were collected for nematological analyses (salad bowl incubation technique). Treatments in the trial were arranged in a randomized complete block design and each treatment was represented by 8 replications (plots).

Statistical Analyses. Variables studied in the experiments were weed and nematode numbers. Data from the experiments were analyzed by standard procedures for analyses of variance. When F values were significant ($p \leq 0.01$) differences among means were evaluated for significance according to Duncan's multiple range test. Unless otherwise indicated differences referred to in the text were significant at $p \leq 0.01$.

RESULTS

Greenhouse Experiments. Numbers of the reniform and microbivorous nematodes declined sharply in response to increasing PO rates up to 750 mg/kg soil; dosages ≥750 mg/kg soil resulted in 100% kill. The same pattern of response to PO applications was observed for soil and root populations of *R. reniformis* at termination of the experiment 8 weeks after planting (Figure 1). Significant populations of microbivorous nematodes were observed in control and all PO-treated soils at the end of the experiment; soil and root populations of these nematodes increased directly in response to PO dosages between 125-1000 mg/kg soil but declined in soils treated with rates ≥1125 mg. Weights of fresh roots and shoots were increased by all PO rates but the highest increase for the two variables was observed in response to the lowest PO dosage. In other greenhouse trials, application of a 5% aqueous PO solution to a soil infested with crabgrass (*Digitaria sanguinalis*), yellow nutsedge (*Cyperus esculentum*), Jimson weed (*Datura stramonium*) and a variety of other weed species resulted in 100% control of all weeds at rates >600-800 mg ai/kg soil.

Microplot Experiment. Results from the microplot experiment demonstrated that PO injected directly into soil to a depth of 36 cms (14 inches) and covered with polyethylene was effective in controlling nematodes and yellow nutsedge and other weeds at rates of ≥ 12 ml/meter row (approx. 25-30 gal/A, depending on bed or row width. Drenching soil with a 20% aqueous solution of PO was 40-50% less effective than direct injection of the chemical for control of weeds in the microplots (Figures 2A and 2B).

CONCLUSIONS

PO is a wide spectrum soil fumigant. Results from experiments at Auburn University indicate that direct injection of the undiluted chemical into soil is more efficacious than applications based on delivery of aqueous solutions by drenching soil. Data from these experiments considered with current price, commercial availability, and relatively low mammalian toxicity indicate that PO has great potential for development as an alternative to MB for fumigation of soils.

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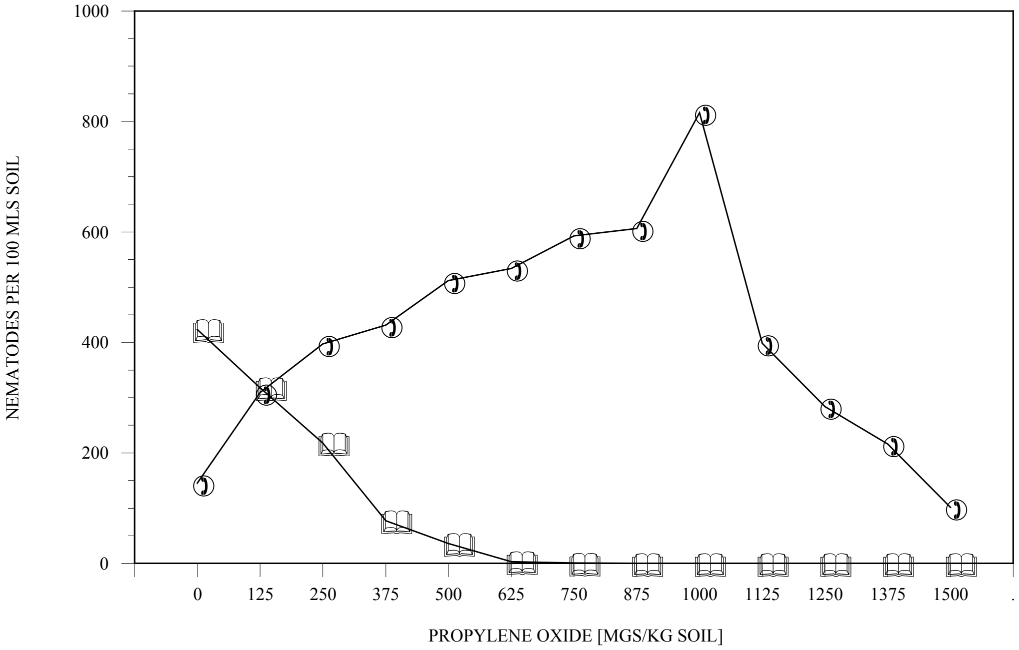

Figure 1: Effect of applications of propylene oxide on final populations of reniform nematode (*Rotylenchulus reniformis*.; diamonds) and microbivorous nematodes (circles) in a greenhouse experiment (1.0 mg/Kg soil is approximately equivalent to 2 kgs/ha)

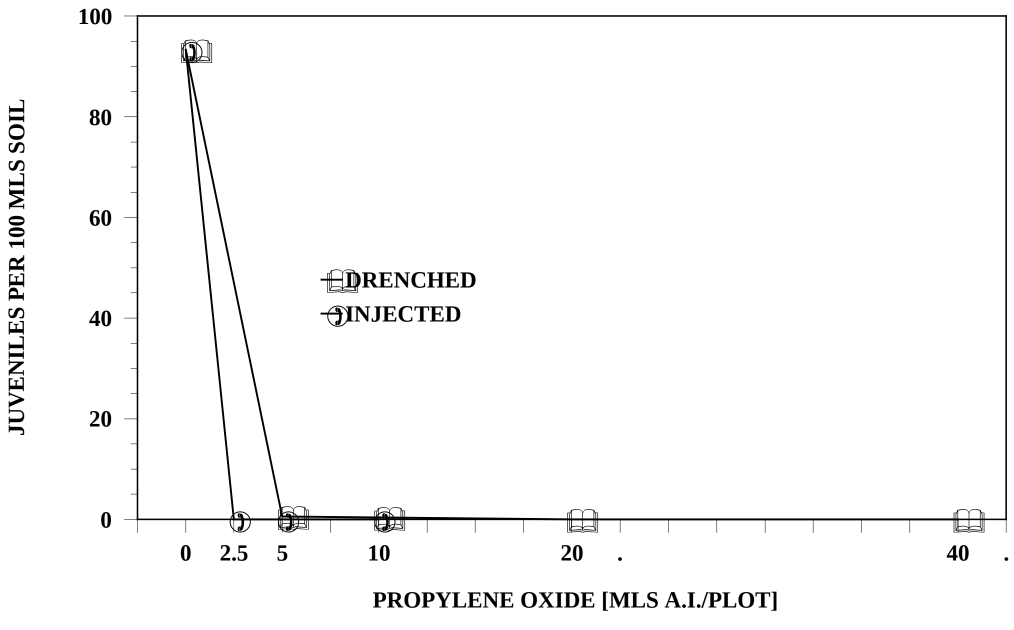

Figure 2A: Effect of drenched (diamonds) and direct injection (circles) applications of propylene oxide on populations of root-knot nematodes (*Meloidogyne* spp.) in a microplot experiment at Auburn University's microplot facilities (1 ml/plot is approximately equivalent to 32 L/Ha on a 1 meter-wide bed basis).

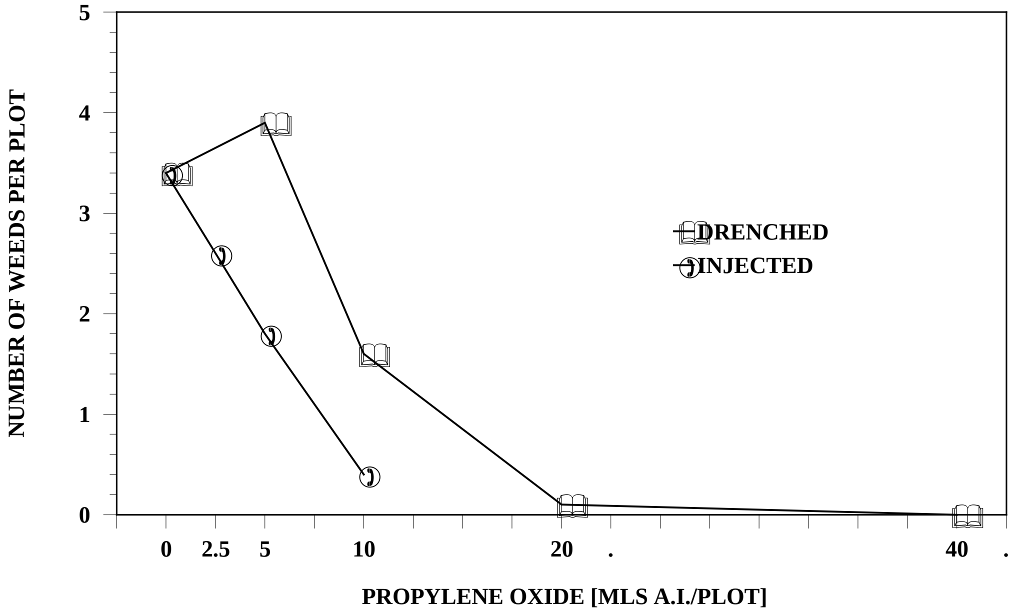

Figure 2B: Effect of drenched (diamonds) and direct injection (circles) applications of propylene oxide on populations of yellow nutgrass (*Cyperus esculentum*) in a microplot experiment at Auburn University's microplot facilities (1 ml/plot is approximately equivalent to 32 L/Ha on a 1 meter-wide bed basis).

METHYL BROMIDE PROJECTS IN DEVELOPING COUNTRIES
- ROLE OF THE MONTREAL PROTOCOL AND GTZ

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ABSTRACT

The GTZ poster provides information about major uses of methyl bromide (MB) in developing countries, and changing patterns of MB consumption, including trends in Morocco, Turkey and other major consumers. It gives an overview of the Montreal Protocol MB projects in developing countries, information about the crops/uses covered, and a summary of the results available to date. It also describes GTZ's approach to MB phase out and results of the GTZ projects, highlighting information relevant to MB users in Europe.

Keywords: developing countries, GTZ, methyl bromide, alternatives

METHYL BROMIDE USE PATTERNS

Developing countries use MB for the same purpose as European users: to control a wide range of pests/diseases in high-value horticultural crops and commodities. Approx. 70% of MB used in developing countries is for soil fumigation - for crops such as strawberry, tomato, pepper, cucurbits, cut flowers and tobacco seedbeds. The remainder is about 20% for durable commodities (eg. grains), 8% for perishable commodities (eg. quarantine treatments of fresh fruit) and about 3% for structures (MBTOC 1998). These estimates are due to be up-dated by MBTOC in 2002.

In 1998, developing countries used about 17,760 tonnes MB for soil and stored products, plus an additional amount (which is very difficult to quantify) for quarantine and pre-shipment (QPS). Developing countries accounted for approx. 25% of global MB consumption in the late 1990s.

Table 1 shows that MB use (excluding QPS) in developing countries increased by about 40% between 1994 and 1998. However, preliminary data for 1999 and 2000 indicate that MB consumption has stabilised or fallen in many countries. This change is largely a result of the Montreal Protocol activities and MB projects which are being carried out in most regions.

TABLE 1: MB consumption trends in developing countries 1994 - 1999, excluding QPS

Year	MB consumption excl. QPS (tonnes)
1994	12,790
1995	14,405
1996	14,424
1997	15,467
1998	17,760
1999	15,500 preliminary estimate

In 1998 MB consumption in developing regions was greatest in Latin America (41%), followed by Asia/Middle East (29%) and Africa (29%) (Table 2). The use patterns for MB vary greatly from region to region. In Latin America MB is used primarily for soil fumigation. In Asia it is used mainly for grains and other durable commodities, with the exception of China which uses MB mainly for soil fumigation. In Africa it is used for both soil and commodities.

TABLE 2: Reported methyl bromide consumption by region in 1998, excluding QPS

Developing regions	MB consumption excl. QPS (tonnes)	
Latin America & Caribbean	7,206	41%
Africa	5,143	29%
Asia, Middle East & Pacific	5,156	29%
CEIT	257	1%
Total developing countries	17,760	100%

Use patterns also differ greatly from one country to the next, even among those who grow similar crops. Analysis of 84 developing countries found that 70% used less than 50 tonnes MB per year, while 12% consumed more than 500 tonnes:

- 12 (14%) countries consumed zero MB
- 47 (56%) consumed less than 50 tonnes MB
- 16 (19%) consumed 50 - 500 tonnes MB
- 10 (12%) consumed more than 500 tonnes MB

In 1999, the countries consuming more than 500 tonnes MB were: Argentina, China, Costa Rica, Egypt, Guatemala, Mexico, Morocco, South Africa, Turkey and Zimbabwe.

MONTREAL PROTOCOL CONTROLS

Traditionally, the Montreal Protocol schedules have allowed ten extra years for developing countries to phase out ozone-depleting substances. MB consumption will be frozen in developing countries in 2002 (at 1995-98 average level), followed by a 20% reduction in 2005 and phase-out by 2015, excluding QPS. In 2003, the Montreal Protocol will review this schedule and may decide to introduce additional reductions.

However, the Protocol encourages all countries to phase out ozone-depleting substances faster than the international schedule, wherever possible. The Protocol's Multilateral Fund (MF) provides assistance for developing countries to do this, in partnership with UNEP, UNDP, UNIDO, the World Bank, and development agencies of industrialized countries such as Australia, Canada and Germany (GTZ). By the end of 2001, the MF had approved MB projects in more than 50 countries, comprising 44 demonstration projects to transfer and adapt alternatives, and more than 50 projects which provide information, technical assistance, training and/or policy development. Recently, the MF has approved 26 projects which plan to reduce and phase out major uses of MB in key developing countries, by encouraging the supply of alternative products and services, training growers how to use alternatives, introducing controls on MB imports, and making national action plans; in most cases the countries have made commitments to phase out major MB uses by 2006/7 at the latest.

For example, Turkey will introduce alternatives for tomato, cucumber, cut flowers and dried fruit, and has made a commitment to reduce MB imports/consumption from 840 tonnes in 1997 to 34 tonnes in 2006. Morocco has several projects that will introduce alternatives for major crops, and plans to reduce MB imports/consumption from 1,600 tonnes in 1998 to 275 tonnes in 2006. A number of countries who export to the EU aim to phase out MB early, because they expect that, as 2005 approaches, European retailers, food manufacturers and agricultural organisations may press for labelling or other measures to discourage developing countries from using MB fumigation.

GTZ APPROACH

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) implements technical co-operation with developing countries on behalf of the German Ministry for Economic Cooperation and Development (BMZ). Early phase-out of MB has been given high priority in its environmental and rural development activities.

GTZ is working with partner countries to adapt and implement alternative production systems that are environmentally sound and economically viable, meeting the long-term needs of farmers, rural communities, purchasing companies and consumers. MB projects include components such as the development of action plans, MB import controls, awareness raising, policy dialogue with growers, trials to adapt and improve alternatives for local conditions, training programs for farmers and extension personnel, investment assistance, and development of new local industries to supply alternative products and services. GTZ focuses on farmers and farm-based activities, favouring a participatory process that fully involves farmers, agricultural organizations and other stakeholders. Projects are designed to build up local expertise and capabilities, so that changes and improvements will have a lasting impact.

When selecting suitable alternatives for technology transfer, projects typically review the available information from MBTOC and other technical sources about alternatives used commercially by farms in relevant climates/conditions. Examples of alternative techniques in commercial use are listed in Tables 3 to 7. Frequently, several techniques have to be combined in order to control the wide range of pests that MB controls. So an IPM approach has proved very useful in the process of selecting alternatives: identifying the target pests, identifying the effective controls for each pest in turn, and then selecting combinations of treatments or practices to control the full spectrum of pests in the location.

TABLE 3: Examples of alternative techniques used for tomatoes and peppers

Alternative techniques	Examples of commercial use
Solarisation + IPM	Jordan, Morocco, Japan, Israel, USA
Steam	Belgium, Netherlands, UK
Substrates	Canary Islands, Morocco, Spain, Belgium, Canada, Denmark, Netherlands, UK
Resistant varieties, grafting	Developing countries, Japan, Morocco, Spain, USA
Fumigants	Egypt, Jordan, Lebanon, Morocco, Tunisia, USA, Europe

TABLE 4: Examples of alternative techniques used for strawberries

Alternative techniques	Examples of commercial use
Solarisation	Jordan, various industrialised countries
Substrates	Malaysia, Indonesia, Netherlands, UK
Organic amendments, composts	Many countries
Crop rotation	Many countries
Resistant varieties	Japan, Denmark
Fumigants	Egypt, Jordan, Lebanon, Morocco, Tunisia, Netherlands, Spain, UK

TABLE 5: Examples of alternative techniques used for cut flowers

Alternative techniques	Examples of commercial use
Solarisation	Lebanon, industrialised countries
Steam + IPM	Colombia, Europe
Substrates	Brazil, Canada, Europe
Organic amendments, composts	Many countries
Crop rotation	Many countries
Resistant varieties	Many countries
Fumigants	Brazil, Colombia, Costa Rica, Morocco, non-A5 countries

Compiled from: MBTOC 1998

TABLE 6: Examples of alternative techniques used for tobacco seedbeds

Alternative techniques	Examples of commercial use
Substrates, float system	Brazil, South Africa, USA
Biofumigation	South Africa, Zimbabwe, USA
Fumigants	Brazil, Japan, USA

Compiled from: MBTOC 1998

TABLE 7: Examples of alternatives used for grains and other stored products

Alternative treatments	Examples of countries where alternatives have been used
Phosphine	Germany, Philippines, Thailand, UK, Zimbabwe and many other industrialised and developing countries
Carbon dioxide	Australia, Indonesia, Philippines, Vietnam
In-transit carbon dioxide	Australia
In-transit phosphine	Europe, USA
Phosphine mixed with carbon dioxide or nitrogen	Australia; Cyprus and Germany
Nitrogen	Australia, Germany
Gas-flushed retail packs	Thailand (commercial trial)
Hermetic storage	Israel, Philippines
Vacuum chamber	Indonesia
Heat treatment	Australia (prototype)
Cold treatments	Mediterranean, USA
Freezing	Europe (for premium grains)
Inert dusts (where conditions appropriate)	Australia, Canada, Germany

Compiled from: MBTOC 1998, Prospect 1997, GTZ 1998, USDA-APHIS 1998

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EFFECTS OF CHEMICAL AND NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE ON STRAWBERRY NEMATODES IN SOUTHERN SPAIN

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ABSTRACT

Two field trials were made each year between 1998 to 2001 in two localities of Huelva, the strawberry area of southern Spain. An assay included chemical alternatives to methyl bromide (MB) soil fumigation, and another one composed of non-chemical alternatives including solarization and biofumigation. Plot situation was repeated each year but plot treatments differed by slight changes on the kind or amount of the fumigant employed. Plants were harvested at the end of each season and the incidence and severity of knotted roots were recorded, number of *Meloidogyne hapla* females were also measure. Some chemical alternatives, like Telopic (DD+chloropicrin) or chloropicrin, showed a very effective nematode control, however the non-chemical alternatives were not successful. The lesion nematode, *Pratylenchus penetrans,* had reduced populations but, to a certain extent, showed a similar behaviour. Linear coefficients of correlation between disease measures and yield or agronomic traits were estimated in these fields, and it is possible to conclude that at least a part of crop losses could be explained by the presence of the root-knot nematode on strawberry roots.

Keywords: strawberry, methyl bromide, *Meloidogyne hapla*, alternatives, nematodes.

MATERIALS AND METHODS

During 1997-98 to 00-01 seasons, as part of INIA SC 97-130 National Project, assays on MB alternatives were made in the localities of Cartaya and Moguer, representative of the strawberry production area of Huelva, southern Spain. A chemical alternatives and a non-chemical alternatives experiment, disposed as a randomised complete block design with three replications, was performed each year for each locality.

The experiment was considered dynamic in a sense that treatment of a specific plot could be changed along years using new technologies, such as Preformed beds (Pb) and/or mulched with VIF plastic that allowed a reduction in the amount of fumigant applied. Fumigation methods and cultural practices were described previously (López-Aranda *et al*. 2001). A four year summary of the treatments is presented in Table 1.

Table 1: Summary of preplant soil fumigation treatments sequence through the years.

Plot treatments	Year 98	Year 99	Year 00	Year 01
Chemical alternatives:				
Control	Control	Control	Control	Control
Metam Na	MB (67%) Pb 40[1]	Metam Na Pb 125	Met Na Pb 175	Metam Na Pb 175
Dazomet	MB (67%)[2] 20	Dazomet 50	Dazomet 45	Dazomet Pb 50
MB Pref. beds	MB (67%)[2] Pb 40	MB (50%)[2] Pb 20	MB (50%)[2] Pb 20	MB (50%)[2] Pb 20
Telopic	Telone C17 60	Telone C35 40	Telone C35 Pb 40	TeloneC 35 Pb 40
Chloropicrin	Chlorop 40	Chlorop 40	Chlorop Pb 40	Chlorop Pb 40
MB	MB (67%) 40	MB Pb (50%) 40	MB (50%) Pb 40	MB (50%) Pb 40
Non-chemical alternatives:				
Control	Control	Control	Electromag.wav	Electromag.wav

Plot treatments	Year 98	Year 99	Year 00	Year 01
Solarization	Solarization	Solarization	Solarization	Solarization
Biofumigation	Biofumigation	Biofumigation	Biofumigation	Biofumigation
Sol+Metam Na	Sol+Metam Na 50	Sol+Met Na 100	Sol+Metam Na 75	Sol+Metam Na 75
Sol+MB/Telopic	Sol+MB (67%) 10	Sol+MB (50%) 10	Sol+MB (50%) 10	Telone C35 Pb 20
MB	MB (67%) 40	MB (67%) 40	MB (67%) 40	MB (67%) 40

1: g/m^2 or cc/m^2 . 2: with VIF plastic.

Before planting, a sample of plants was analysed (nematodes were never found). At the end of the season 10 plants/plot were collected with their complete root system carefully washed, observed under binocular microscope and nematodes were extracted from 25 g of roots using the sugar centrifugation method. *Meloidogyne hapla* and *Pratylenchus penetrans* were the species present. Diseased roots were also evaluated with a 0-4 scale (0=No symptoms; 4=more than 95% of root system galled). Data obtained or transformed as log, sqr or arcsen were analysed as serial experiments (MSTATC 2.1).

RESULTS AND DISCUSSION

Table 2: Measurement of disease caused in Strawberry plants by *M. hapla* after different soil fumigations with chemical alternatives.

	Location: Cartaya[1]			Location: Moguer[1]		
	Incidence[2]	Severity[3]	♀/g [4]	Incidence[2]	Severity[3]	♀/g [4]
Control	73.5 a[5]	2.23 a	13.6 a	2.5 a	0.42 a	8.37 a
Metam Na	55.5 b	1.65 b	12.4 a	0.0 b	0.00 a	0.00 a
Dazomet	16.2 c	0.84 c	5.2 b	0.0 b	0.00 a	0.00 a
MB Pref. beds	15.0 c	0.64 c	1.3 b	0.0 b	0.00 a	0.00 a
Telopic	7.7 c	0.47 c	0.4 b	0.0 b	0.00 a	0.00 a
Chloropicrin	7.6 c	0.50 c	0.5 b	0.0 b	0.00 a	0.00 a
MB	7.5 c	0.39 c	0.5 b	0.0 b	0.00 a	0.00 a

1: Mean of 10 plants/plot, 3 blocks/year and 4 years; 2: Percentage of disease plants; 3: Severity (0=no symptoms; 4=more than 90% of roots affected); 4: Number of females/g of roots; 5: Means followed by the same letter are not different under a MDS test, ($P<0.05$).

Results on Table 2 showed that at Cartaya the best nematode control was obtained with Telopic (DD+Chloropicrin), Chloropicrin and MB. Abbot´s efficacies respective to nonfumigated tests were over 75% and reached 97% in Telopic control of female number.

Table 3: Measures of disease caused in Strawberry plants by *M. hapla* after different soil fumigation with Non-chemical alternatives.

	Location: Cartaya[1]			Location: Moguer[1]		
	Incidence[2]	Severity[3]	♀/g [4]	Incidence[2]	Severity[3]	♀/g [4]
Control	54.2 a[5]	2.01 a	13.5 a	15.0 a	0.99 a	13.1 a
Solarization	36.7 a	1.48 ab	5.8 ab	8.3 ab	1.20 a	10.3 a
Biofumigation	32.5 ab	1.10 bc	5.0 ab	0.8 b	0.25 b	0.2 a
Sol+ Metam Na	26.7 b	0.63 bcd	3.6 bc	0.0 b	0.00 b	0.0 a
Sol+MB/Telopic	12.5 b	0.72 cd	1.7 bc	0.0 b	0.00 b	0.0 a
MB	0.8 c	0.08 d	0.0 c	0.0 b	0.00 b	0.0 a

1-5: As indicated in Table 2.

Solarization and biofumigation(Table 3) were not effective in controlling disease compared to Solarization+MB/Telopic or MB, used as chemical checks between the non-chemical alternatives. A similar result was obtained for *P. penetrans* at Cartaya location where the largest population was found.

Table 4: Lineal Correlation coefficients between Disease measures and Agronomic traits[1]

	Severity	♀/root g	Plant diameter	Number of leaves	Fruit size	Yield
Incidence	0.791 ***	0.579 ***	**-0.212 *** **	**-0.192 *** **	**-0.426 *** **	**-0.361 *** **
Severity	-------	0.678 ***	**-0.237 *** **	**-0.197 *** **	**-0.459 *** **	**-0.347 *** **
♀/root g		-------	**-0.006** ^{NS}	**-0.085** ^{NS}	**-0.291 *** **	**-0.141 ** **
Plant diameter			-------	0.409 ***	0.328 ***	0.652 ***
Leaf number				-------	0.350 ***	0.192 ***
Fruit size					-------	0.465 ***

1: Obtained from 294 or 312 couples of observations; ***: P≤0.001; **: P≤0.010; *: P≤0.050; ^{NS}: P>0.050.

Table 4 shows the correlation coefficients between subjective (severity) and objective (incidence and female number) disease measures in respect to yield or other agronomic traits (plant diameter, number of leaves and fruit size). Because all coefficients were negative we can infer that in these fields part of crop losses could be accounted for by the presence of root knot nematode. Fruit size as a component was especially affected.

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SOLARIZATION AND ITS COMBINATIONS: THE FIRST YEAR RESULTS OF A DEMONSTRATION PROJECT

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ABSTRACT

Methyl bromide (MB) consumption in Turkey increased from 643 tonnes in 1990 to 1319 tonnes in 1998. Turkey plans to phase out MB by 2008 even though the Montreal Protocol does not require phase out until 2015. The Eastern Mediterranean Region of Turkey is one of the foremost agricultural areas and strawberry and vegetable crops have been extensively cultivated. In the region, a World-Bank-supported Project was initiated in 2000 to introduce farmers to MB alternatives for use on strawberry, pepper and eggplant crops. Solarization, and its combinations with dazomet (400 kg/ha), chicken manure (10 tonnes/ha) or straw (500 kg/ha), were demonstrated at various sites. The effect of the treatments on soil borne diseases, weeds, nematodes and crop yield were measured. All alternatives gave comparable results with MB. Combinations of solarization with dazomet or chicken manure seemed effective alternatives. Solarization alone or with *Trichoderma* could be an inexpensive choice. These results and other activities under this project influenced farming agricultural practices in Turkey.

Keywords: strawberry, pepper, eggplant, solarization, dazomet, chicken manure, *Trichoderma*

INTRODUCTION

Methyl bromide (MB) consumption in Turkey increased from 643 tonnes in 1990 to 1319 tonnes in 1998. MB is used for soil fumigation, especially in cut-flowers, strawberry and vegetable crops grown under protected conditions in Turkey. Vegetable cultivation under protected conditions reached 44,000 ha and strawberries 8600 ha in 1999. Strawberry and vegetable crops have been extensively cultivated in the Eastern Mediterranean Region of Turkey. MB is also extensively used (150 tonnes in pepper, eggplant, and strawberry production in the East Mediterranean Region), and the farmers consider no other alternatives. However, solarization and its combinations with chemicals or organic materials are considered as applicable alternatives in Mediterranean conditions.

In the region, a World-Bank-Supported-Project was initiated in 2000 to introduce MB alternatives to strawberry, pepper and eggplant producers in order to meet Turkey's plan to phase out MB by 2008 even though the Montreal Protocol allows a MB phase out by 2015. In this paper, the first year's results of the demonstration projects with solarization and its combinations will be presented.

MATERIALS AND METHODS

Treatments were carried out successfully at 9 sites consisting of 6 pepper plastic houses, a strawberry plastic house, an open field strawberry crop and an open field eggplant crop. Treatments, number of replicates and plot sizes differed due to field size and crop. Combinations of solarization with dazomet (400 kg/ha), chicken manure (10 tonnes/ha) or *Trichoderma* spp. were applied to all fields. Combination of solarization and straw at 500 kg/ha was applied in a pepper plastic house. Following application of dazomet, chicken manure or straw, plots were covered with plastic tarp. In strawberry planting ridges were prepared before covering. *Trichoderma* spp. was applied firstly at seed beds, then periodically once a month with drip irrigation. Non-treated and/or MB-applied checks were set in suitable fields. Demonstrations lasted 4-6 weeks except for strawberries that continued for 3 and 7 weeks during July and/or August. The usual cultivation processes were applied during the growing season. Demonstrations were assessed periodically for soilborne diseases, nematodes and weeds. Yield was also recorded.

RESULTS AND DISCUSSION

In the strawberry demonstration sites, no plant parasitic nematodes were detected but a 20% incidence of *Fusarium oxysporum* and *Rhizoctonia solani* were observed in the check plots. All treatments gave 100% disease control (Table 3). The main problem was weeds but different species were abundant in two demonstration sides. Before transplanting *Cyperus rotundus* was detected at one site (Silifke) and summer annuals such as *Amaranthus* spp. were common in the other site (Yaltir). At the end of the season, weed intensity showed similar trends. Also, in the screen house, the effect of treatments was determined in pots, which were filled with soil taken after the tarp was removed from the field. Table 1 shows the average weed intensity in a square meter at early and late field counts and total germinated weed number in soil samples. A total herbicide was applied before transplanting in all treatments except MB treated plots in Silifke, and MB applied plots in Yaltir. Plants were transplanted earlier at MB applied plots in Yaltir. In Silifke, even solarization alone gave acceptable yields but *C. rotundus* control was not satisfactory. On the contrary, in Yaltir there was very good weed control but MB gave the best yield. However, solarization with dazomet seemed to be an alternative to MB.

TABLE 1. Effect of treatments on weeds and total yield in strawberry demonstration sites.

Treatment	SILIFKE				YALTIR			
	Weed intensity				Weed intensity			
	Early	Late	Pot	Yield (t/ha)	Early	Late	Pot	Yield (t/ha)
Solarization	50	105	67	23	18	6	3	30
Solarization+Dazomet 40	35	46	40	24	4	9	4	44
Solarization+Manure	50	57	42	25	6	9	9	32
Methyl Bromide	1	0	8	22	NA	NA	NA	50
Untreated check	NA	NA	NA	NA	NA	33	69	NA

[1]NA: Not applicable

TABLE 2. Effects of treatments on the nematode population as percentage of nontreated check during the growing season.

DATE	TREATMENTS and CONTROL RATES (%)[1]				
	Solarization+Basamid	Solarization+Trichoderma	Solarization+ Manure	Solarization+ Straw	MB
03.10.2000	100.0	100.0	100.0	100.0	100.0
19.10.2000	98.8	100.0	100.0	100.0	100.0
07.11.2000	100.0	100.0	100.0	100.0	100.0
28.11.2000	89.9	100.0	80.0	100.0	97.8
19.12.2000	100.0	100.0	100.0	100.0	100.0
09.01.2001	96.3	99.2	79.9	99.3	100.0
30.01.2001	99.7	100.0	100.0	100.0	99.3
20.02.2001	100.0	100.0	100.0	100.0	97.0
13.03.2001	100.0	99.3	99.9	98.1	97.9
03.04.2001	79.7	98.7	96.2	94.3	91.6
25.04.2001	99.5	95.5	99.8	70.9	90.4
16.05.2001	72.9	88.8	94.4	93.2	87.4
06.06.2001	74.6	91.4	95.8	99.6	59.4
23.07.2001	40.8	59.3	84.9	0.0	0.0

[1]100 is complete control and 0 shows no control

Fusarium spp. were detected in pepper demonstration sites. MB and solarization with dazomet gave better disease control compared to other treatments (Table 3). Weed flora varied among fields but *Portulaca oleracea, Seteria* spp., *Amaranthus* spp., *Solanum* spp., *Echinochloa colona, Seteria viridis, Eluicina indica* and *C. rotundus* were common. Solarization+dazomet was the best control among MB alternatives. In general, solarization alone and solarization+manure gave satisfactory weed control. Pepper fields were heavily infested with *Meloidogyne* spp. Galling index was assessed using Zeck Scale and overall averages of six pepper plastichouses were 0.10, 0.89, 0.98, 1.92, 2.04, and 5.95 for solarization+ *Trichoderma*, solarization+manure, solarization+dazomet, MB, solarization+straw, and check, respectively.

Table 2 shows the effects of treatments on the second term infective larva of the nematode. Combinations of solarization with basamid, manure or *Trichoderma* were the most effective applications. MB and solarization+straw was partially effective. However, it can be said that all treatments effectively controlled nematodes.

Plant parasitic nematode was not detected at the eggplant demonstration site. The treatments controlled weeds but not very well. However, broomrape control was almost 100% in all treated plots. Also, broomrape infestation was seen in mid-April in non-treated checks, which was two weeks earlier than solarized areas. *Fusarium oxysporum* and *Sclerotinia sclerotiorum* were observed in the field. Solarization+dazomet controlled diseases better than solarization+*Trichoderma* or solarization+manure (Table 3).

TABLE 3: Average disease incidence for pepper, eggplant and strawberry in the demonstration sites.

CROP	TREATMENTS AND DISEASE RATES (%)					
	Solarization + Basamid	**Solarization + Manure**	**Solarization + *Trichoderma***	**Solarization + Straw**	**MB**	**CHECK**
Pepper	2.5	7.5	7.5	7.5	0.0	32.5
Eggplant	20.0	37.5	31.2	NA	NA	57.5
Strawberry	0.0	0.0	NA	NA	0.0	20.0

TABLE 4: Yield results in pepper and eggplant demonstration fields

Crop/Field	TREATMENTS AND YIELD (TONNES/HA)				
	Solarization + Basamid	**Solarization + Manure**	**Solarization + *Trichoderma***	**MB**	**Check**
Pepper 1	89	75	70	NA	61
Pepper 2	95	96	85	108	48
Pepper 3	81	94	81	88	60
Eggplant	105	112	91	NA	NA

Solarization and its combinations gave comparable results to MB in controlling nematodes, diseases and weeds, and crop yield (Tables 1 and 4). Combinations of solarization with dazomet or chicken manure seemed effective alternatives. Solarization alone or with *Trichoderma* can be an inexpensive choice. This results and other activities under this project influenced farmers as in this growing season (2001-2002) more farmers applied solarization. Solarization with manure was the most popular combination. It is apparent that there is need for further research related to solarization such as duration, humidity, timing, and other alternative combinations as well as demonstration of the treatments.

DICHLOROPROPENE WITH CHLOROPICRIN APPLIED BY DRIP IRRIGATION AS A VIABLE ALTERNATIVE TO METHYL BROMIDE IN SWEET PEPPER GREENHOUSES

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ABSTRACT

Methyl bromide (MB 98:2) soil fumigation is commonly used to control the soil borne pathogens *Phytophthora capsici* and *Meloidogyne incognita* and to maintain acceptable yield levels in the 1,800 ha of sweet pepper grown in the Southeast of Spain (Murcia and Alicante). The restriction in MB use led to testing a blend of dichloropropene and chloropicrin (TELOPIC: Telone C-35, 60.5% of 1,3-dichloropropene and 33.3% of chloropicrin) applied through a drip irrigation system under plastic mulch as an alternative to MB. In the last three growing seasons, trials were undertake to determine: i) the adequate rate of applications, ii) the method of application and plastic setting, iii) the effect of reiterated application, compared to MB applied at the normal dose (60 g/m^2 of MB 98:2). In commercial greehouses with different phytopathological problems, the effect of treatments on *P. capsici* and *M. incognita*, weeds, plant development and yield were measured.

The best results were obtained at doses from 400 l/ha to 500 l/ha applied under polyethylene mulch (PE). The use of VIF plastic (Virtually Impermeable Film) improved the results and allowed a reduction in the application rate. The orientation of the plastic, in relation to the direction of the drip irrigation tape, did not have any influence on the efficacy of disinfection. Applications of Telopic at 400 l/ha repeated over three years in the same soil gave the same level of control of *P. capsici* and weeds, and produced the same yield and plant development as MB at 60 g/m^2 with PE. The control of *M. incognita* was slightly less than with MB.

Key words: dichloropropene, chloropicrin, sweet pepper, greenhouses, methyl bromide alternatives.

INTRODUCTION

Meloidogyne incognita and *Phytophthora capsici* are the main soil borne pathogens in the 1,800 ha of greenhouse peppers grown in the Murcia region and the south of Alicante. In this area, peppers have been cultivated over the last eighteen years. This monoculture is grown in more that 95% of the area. Soil is disinfected every year with methyl bromide (MB 98:2) in order to control soil borne pathogens and to compensate for yield losses caused by crops repeatedly grown on the same land. Since 1998, due to a restriction on MB use, the mixture dichloropropene and dichloropicrine (Telopic EC: Telone C-35; 1,3-dichloropropene (60.5%) + chloropicrin (33.3%) from Dow Agrosciences) was trailled as an alternative to MB with its broad spectrum of activity. Applications were done by drip irrigation under a plastic mulch.

MATERIALS AND METHODS

The trials were carried out in commercial greenhouses known to have problems with *P. capsici* and *M. incognita* and where peppers have been grown for more than twelve years. The aims of the trials were:

Trial a) To determine the application rate the following treatments were assayed: T1 – Telopic at 300 l/ha with 0.05 mm PE plastic; T2 – Telopic at 400 l/ha with 0.05 mm PE plastic; T3 – Telopic at 500 l/ha with 0.05 mm PE plastic; T4 – Telopic at 200 l/ha with 0.04 mm VIF plastic; T5 – Telopic at 300 l/ha with 0.04 mm VIF plastic; T6 – MB 98:2 at 60 g/m^2 with 0.05 mm VIF plastic; T7 – Control. Non treated soil.

Trial b) Plastic set up was assayed for the following applications: T1 – MB 98:2 at 60 g/m^2 with 0.05 mm VIF plastic; T2 – Telopic at 500 l/ha with 0.05 mm PE plastic in the same direction as irrigation tape; T3 – Telopic at 500 l/ha with 0.05 mm PE plastic perpendicular to the irrigation tape; T4 – Telopic at 400 l/ha with 0.05 mm PE plastic perpendicular to the irrigation tape; T5 – Telopic at 400 l/ha with 0.04 mm PE plastic perpendicular to the irrigation tape; T7 – Control. Non treated soil.

Trial c) Reiteration of Telopic application in the same soil. Two assays were carried out in two greenhouses every year. Trial 1999/2000: T1 – Telopic 2 years at 50 gl/m^2 with 0.05 mm PE plastic; T2 – MB 98:2 at 60 gl/m^2 with 0.05 mm PE plastic; T3 – Control. Non treated soil. Trial 2000/2001: T1 – Telopic 3 years at 50 gl/m^2 with 0.05 mm PE plastic; T2 – MB 98:2 at 60 gl/m^2 with 0.05 mm PE plastic; T3 – Control. Non treated soil.

In all the experiments, the pepper variety Orlando was grown at 2.5 plants/m^2. Growing seasons were from December to the end of August. Treatments were randomized in a complete block design with four replicates per treatment. The following parameters were measured to determine application efficacy: percentage of plants killed by *P. capsici*, percentage of plants infested by *M. incognita*, average *M. incognita* root-knot index (0-10, according to Bridge and Page 1980), plant height, marketable yield and weed soil colonization index (0-3). In all cases, the plastic was kept on the soil for 21 days. Applications were carried out in November. Telopic was applied by Venturi and MB by fumigation.

RESULTS

Rate of application

When the application was done under PE plastic, the best results were obtained using the 500 and 400 l/ha rates. There were no significant differences between any of the parameters tested. When the application was done under VIF plastic, there was an improvement in efficacy that makes it possible to reduce the rates of application. In all the cases, *P.capsici* control was significantly better with MB (98:2) than with Telopic (Table 1).

Table 1. Results of disinfection at different Telopic rates applied by drip irrigation.

	% plants *P. capsici*	% plantas *M. incognita*	Average knot index (1)	Plant height (cm)	Marketable yield (kg/m^2)	Weed index (1-3)
Telopic 300PE	21.7 c	16.6 ab	0.6 abc	105.7 b	7.8b	0.2 a
Telopic 400PE	8.6 b	0.0 a	0.0 a	112.0 ab	9.0 ab	0.1 a
Telopic 500PE	4.9 b	4.1 ab	0.1 a	117.0 a	8.9 ab	0.1 a
Telopic 200VIF	10.7 b	8.3 ab	0.3 ab	116.2 a	9.1 a	0.2 a
Telopic 300VIF	6.9 b	20.8 b	1.1 bc	111.8 ab	8.8 b	0.1 a
MB 60	1.3 a	0.0 a	0.0 a	119.1 a	10.1 a	0.1 a
Control	50.1 d	25.0 b	1.1 c	83.0 c	3.8 c	0.8 b

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. (1) According to Bridge and Page (1980).

Plastic set up

Non significant differences were found between longitudinal and perpendicular settings for any of the parameters tested. Therefore, commercial application is viable as cost is reduced. VIF plastic enhanced Telopic disinfection efficacy. The results yielded with Telopic were similar to MB 60 (Table 2).

Table 2. Influence of plastic setting on Telopic application by drip irrigation

	% plants *P. capsici*	**% plantas** *M. incognita*	**Average knot index (1)**	**Plant height (cm)**	**Marketable yield (kg/m^2)**	**Weed index (1-3)**
MB 60	5.0a	15.8 a	0.4a	158.8a	10.4a	0.08a
Telopic 500PE Long.	15.3abc	10.0a	0.4a	150.2b	9.9a	0.04a
Telopic 500PE Perp.	20.6bc	15.0a	0.5a	153.7ab	9.7a	0.00a
Telopic 400PE Perp.	28.6c	30.0a	0.7a	149.6b	9.6a	0.26a
Telopic 400VIF Perp	11.9ab	20.0a	0.6a	156.0ab	10.7a	0.00a
Control	79.0d	85.0b	5.1b	78.0c	3.3b	2.13b

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. (1) According to Bridge and Page (1980).

Reiteration of Telopic application in the same soil

Disinfection efficacy using Telopic at 50 g/m^2 repeatedly was not different from MB 60. Only in the third year was there a significant reduction in *M. incognita* control, although without any impact in plant growth or marketable yield (Table 3). The results indicate that Telopic EC applied by drip irrigation is an alternative to MB.

Table 3. Results of reiterated use of Telopic applied by drip irrigation.

	% plants *P. capsici*	**% plantas** *M. incognita*	**Average knot index (1)**	**Plant height (cm)**	**Marketable yield (kg/m^2)**	**Weed index (1-3)**
MB 60	0.7 a	3.6a	0.1a	114.3a	8.0a	0.7a
Telopic 2 years	2.6 a	5.4a	0.7a	115.4a	8.5a	0.3a
Control	46.1 b	57.8b	3.2b	74.0b	3.2b	1.5b
MB 60	1.7a	20.0a	0.6a	149.8a	9.2a	0.00a
Telopic 3 years	4.1a	47.5b	2.7b	145.3a	9.3a	0.04a
Control	28.2b	100.0c	6.7c	80.1b	3.8b	4.62b

Means in the same column followed by the same letter are not significantly different (P > 0.05). LSD Test. (1) According to Bridge and Page (1980).

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SPEAKER PROGRAMME INTERNATIONAL CONFERENCE ON ALTERNATIVES TO METHYL BROMIDE, SEVILLA, SPAIN, 5-8 MARCH 2002	
MONDAY 4 MARCH	
16:00 – 20:00	Registration Set up Posters
TUESDAY 5 MARCH	
7:00	Registration
8:00	Set up posters
9:00	**PLENARY 1: WELCOME** **Cochairs:** José M. Bolivar and Tom Batchelor Representatives of the Ministries of Agriculture, Environment, Science and Technology; a representative of the Junta de Andalucia; and a representative of the European Commission
9:25 – 10:30	**PLENARY 2: OZONE DEPLETION, THE MONTREAL PROTOCOL AND EC REGULATIONS** **Co-chairs:** Juan Martínez (MIMAM,Spain) and Jonathan Banks (Australia)
9:25 – 9:45	**José I. Casanova (Spain):** An overview of the scientific aspects of ozone depletion and their impact on the environment
9:45 – 10:05	**Jean Verdebout (Italy):** Documenting UV radiation to support impact studies and health protection for citizens
10:05 – 10:25	**Tom Batchelor (Belgium):** International and European Community controls on MB and the status of MB use and alternatives in the EC
10:25 – 10:30	**Tom Batchelor and José M. Bolivar:** Conference Announcements including a description of Wednesday's Field Tour
10:30 – 11:00	**REFRESHMENTS**

TUESDAY 5 MARCH (continued)				
11:00 – 14:00	**SESSION 1A: STRAWBERRY** **Cochairs:** José M. Bolivar (INIA, Spain) and Rod Rodriguez-Kabana (USA)		**SESSION 1B: QUARANTINE AND PRE-SHIPMENT** **Cochairs:** Juan J. Guitian (MAPA, Spain) and Michelle Marcotte (Canada)	
11:00 - 11:30	Ian Porter (Australia)	Overview: Non-chemical alternatives to MB for soil treatment in strawberry production	Jonathan Banks (Australia)	Alternatives to MB for durable commodities and timber
11:30 – 12:00	John Duniway (USA)	Overview: Chemical alternatives to MB for soil treatment particularly in strawberry production	David Mueller (USA)	Alternatives to MB for disinfestation of structures and food facilities
12:00 – 12:20	José M.López-Aranda (Spain)	Alternatives to MB for use in strawberry production and nurseries in Spain	Christoph Reichmuth (Germany)	Alternatives to MB for treatment of wood, timber and artefacts in the EC
12:20 – 12:40	Paloma Melgarejo (Spain)	The importance of disease-free plants produced in strawberry nurseries in Spain	Magali Raynaud (UK)	Preventative cleaning and inspection as an alternative to MB for treatment of food facilities in the EC
12:40 – 13:00	Vicent Cebolla (Spain)	Alternatives to MB in vegetable and strawberry crops in Spain	Alejandro López de Roma (Spain)	Alternatives to MB for timber treatments
13:00 – 13:20	Mohamed Ammati (Morocco)	Alternatives to MB in strawberries in Morocco	Alan Dowdy (USA)	Non-chemical MB alternatives in the USA
13:20 – 13:40	Adam Szczygiel (Poland)	Alternatives to MB in strawberries in Poland	Josep Jacas (Spain)	Low temperature storage of food and other treatments as an alternatives to MB
13:40 – 14:00	José López-Medina (Spain)	The use of substrates for strawberry production in Spain	Ricardo Deang (Philippines)	Alternatives to MB for use as quarantine and pre-shipment treatments in developing countries
14:00 – 15:15	**LUNCH**			
15:15 – 15:25	**OFFICIAL GROUP PHOTOGRAPH OF ALL PARTICIPANTS IN CONFERENCE**			

TUESDAY 5 MARCH (continued)				
	WORKSHOP 2A STRAWBERRY SESSION **Moderator:** Fernando Romero; **Overview**: John Duniway; **National Expert**: José M. López-Aranda		**WORKSHOP 2B QUARANTINE AND PRE-SHIPMENT** **Moderator:** Tom Batchelor; **Overview**: Jonathan Banks; National **Expert**: Ernesto Santaballa	
15:30 – 15:40	Fernando Romero (Spain)	Moderator: Aims of Strawberry Workshop	Tom Batchelor (Belgium)	Moderator: Aims of QPS Workshop
15:40 – 15:50	John Duniway (USA)	Overview: Alternatives to MB used in strawberry production in the United States	Jonathan Banks (Australia)	Overview: Non-MB Quarantine and pre-shipment treatments
15:50 – 16:00	José M. López-Aranda (Spain)	National: Alternatives to MB in strawberries in Spain	Ernesto Santaballa (Spain)	National: Non-MB Quarantine and pre-shipment treatments used in Spain
16:00 – 16:10	Juan J. Medina-Minguez (Spain)	Case Study: Soil solarisation and biofumigation in strawberries in Spain	Simcha Finkelman (Israel)	Case Study: Application of Vacuum to Sealed Flexible Containers: A Viable Alternative to Disinfestation of Durable Commodities with MB
16:10 – 16:20	Enrique Monte (Spain)	Case Study: *Trichoderma* as an alternative to MB in strawberries	Mike Drinkall (UK)	Case Study: Sulfuryl fluoride for disinfestation of timber and structures
16:20 – 16:30	Rodrigo Rodrigez-Kabana (USA)	Case Study: Azides as alternatives to MB	Jordi Riudavets (Spain)	Case Study: Alternatives to MB for treatment of grain and seeds
16:30 – 16:40	Javier Palacios (Spain)	Case Study: Strawberry nurseries and the use of MB in Spain	David Sánchez (Spain)	Case Study: Electromagnetic fields to control pests in cereal storage
16:40 – 16:50	Manuel Verdier (Spain)	Case Study: Strawberry production and the use of alternatives to MB in Huelva	Andreas Varnava (Cyprus)	Case Study: Hermetic storage of grain in Cyprus
16:50 – 17:00	Moderator: Fernando Romero (Spain)	Comments on case studies	Moderator: Tom Batchelor (Belgium)	Comments on case studies
17:00 – 17:30	**REFRESHMENTS**			
17:30 – 18:30	Moderator: Fernando Romero Discussions		Moderator: Tom Batchelor Discussions	
18:30 – 18:50	Conclusions		Conclusions	
19:00	Close of workshop		Close of workshop	
WEDNESDAY 6 MARCH				
07:30 – 20:00	**FIELD VISITS** Huelva (strawberries) or Cadiz (cut-flowers and vegetables) or Seville environs (postharvest disinfestation) tour ; Depart at 07:30 from Hotel Alcora and arrive back in Seville at approximately 20:00 hours			

THURSDAY 7 MARCH				
	SESSION 3A **TOMATOES AND OTHER VEGETABLES** **Cochairs:** Jose Luis Muriel (CAP-JA, Spain) and Ian Porter (Australia)		**SESSION 3B** **CUT-FLOWERS** **Cochairs**: Manuel López-Rodriguez (Spain) and Ilias Eleftherohorinos (Greece)	
09:00 – 9:30	Julio C. Tello (Spain)	Overview: Tomato production in Spain without MB	Marta Pizano (Colombia)	Overview: Alternatives to MB for use in cut-flower production
9:30 – 10:00	Mohamed Besri (Morocco)	Alternatives to MB for tomato production in the Mediterranean region	José Melero Vara (Spain)	Alternatives to MB for cut-flower production in southern Spain
10:00 – 10:25	Eris Tjamos (Greece)	Alternatives to MB for vegetable production in Greece	Luis Reis (Portugal)	The use of MB alternatives in cut-flower production in Portugal
10:25 – 10:30	José M. Bolivar	Practical Announcements	Tom Batchelor	Practical Announcements
10:30 – 11:00	REFRESHMENTS			
11:00 – 14:00	**SESSION 3A (CONT)** **TOMATOES AND OTHER VEGETABLES** **Cochairs**: Jose L. Muriel and Ian Porter		**WORKSHOP 3B** **CUT-FLOWERS** **Moderator:** Vicent Cebolla; **Overview**: Andrea Minuto; **National Expert**: José M. Melero	
11:00 – 11:20	Alfredo Lacasa (Spain)	Alternatives to MB in sweet peppers in Spain	Moderator: Vicent Cebolla (Spain) 11:00 – 11:05	Aims of QPS Workshop
11:20 – 11:40	Jerome Fritsch (France)	The current status of alternatives to MB in vegetable crops in France		
11:40 – 12:00	Soledad Verdejo (Spain)	Biological control agents in vegetable crops as alternatives to MB	Andrea Minuto (Italy) 11:05 – 11:25	Overview: Use of alternatives to MB for cut-flowers
12:00 – 12:20	Girolamo Cartia (Italy)	Alternatives to MB for tomatoes and vegetables in Italy	José M. Melero (Spain) 11:25 – 11:45	National: MB alternatives for cut-flower production in Chipiona

THURSDAY 7 MARCH (continued)				
12:20 – 12:40	Ali Ozturk (Turkey)	Alternatives to MB for tomato and cucumber production in Turkey	Luis F. Calderón-Bran (Guatemala) 11:45 – 12:05	Case study: Alternatives to MB for cut-flower production in Guatemala
12:40 – 13:00	Eduardo Pérez Montesbravo (Cuba)	Alternatives to MB for soil treatments in Cuba	Ilias Eleftherohorinos (Greece) 12:05 – 12:25	Case study: Alternatives to MB for control of annual and perennial weeds
13:00 – 13:20	Antonio Bello (Spain)	Biofumigation as an alternative to MB	Alfréd Forray (Hungary) 12:25 – 12:45	Case study: IPM and biological control used in the production of cut-flowers in Hungary
13:20 – 13:40	Frans Pauwels (Belgium)	Alternatives to MB for tomato production in Belgium	Juan A. Navas (Spain) 12:45 – 13:05	Case study: The use of alternatives to MB in cut-flower production in Chipiona
13:40 – 13:50	Cochairs Jose L. Muriel and Ian Porter Discussion		Oriol Marfà (Spain) 13:05 – 13:25	Case study: Closed soilless techniques for cut flower production as an alternative to MB in Mediterranean conditions
13:50 – 14:00	Conclusions		Moderator: Vicent Cebolla 13:25 – 14:00	Discussion with workshop participants Summary and Conclusions
14:00 – 15:30	**LUNCH**			
15:30 – 19:00	**WORKSHOP 4: NON-CHEMICAL ALTERNATIVES** **Moderator**: Antonio Bello; **Overview**: John Duniway; **National Expert**: Alfredo Lacasa			
15:30 – 15:40	Moderator: Antonio Bello (Spain)	Aims of Workshop on Non-Chemical Alternatives		
15:40 – 15:50	John Duniway (USA)	Overview: Non-chemical alternatives used in the USA on horticultural crops		
15:50 – 16:00	Alfredo Lacasa (Spain)	National: Use of non-chemical alternatives in Spain		
16:00 – 16:15	Nahum Marban-Mendoza (Mexico)	Case Study: Non-chemical alternatives to MB used in Mexico on vegetable crops		
16:15 – 16:30	Andrés López-Garcia (Spain)	Case Study: Alternatives to MB for sweet peppers grown in greenhouses in Spain		
16:30 – 16:45	Alfredo Miguel (Spain)	Case Study: Non-chemical alternatives used in Spain on vegetable crops		

THURSDAY 7 MARCH (continued)		
16:45 – 17:00	Majid Fandi Zubi (Jordan)	Case Study: Non-chemical alternatives used in Jordan on horticultural crops
17:00 – 17:30	**REFRESHMENTS**	Location:
17:30 – 17:45	Eris Tjamos (Greece)	Case Study: Non-chemical alternatives used in Greece on horticultural crops
17:45 – 18:00	Gordana Popsimonova (Macedonia)	Case Study: Non-chemical alternatives used in Macedonia on vegetables
18:00 – 18:50	Moderator: Antonio Bello	Discussion
18:50 – 19:00	Moderator: Antonio Bello	Conclusions

FRIDAY 8 MARCH		
	PLENARY 3: ECONOMIC AND SOCIAL Location: **Co-chairs:** Maria C. Fernández-Durántez (Spain) and Alan Dowdy (USA)	
9:00 – 9:30	Melanie Miller (Belgium)	Measures and activities that assist with the phase out of MB
9:30 – 10:00	Lori Lynch (USA)	The economic impact of the phase out of MB on agriculture in the USA
10:00 – 10:25	Laslo Kovacs (Hungary)	The economic impact of the phase out of MB on horticultural producers in Hungary
10:25 – 10:30	Tom Batchelor & José M. Bolivar	Practical Announcements
10:30 – 11:00	**REFRESHMENTS** Location:	
11:00 – 11:20	Pedro Caballero (Spain)	Economic evaluation of MB alternatives used on the east coast of Spain
11:20 – 11:40	Javier Calatrava (Spain)	Southwestern Spain strawberry grower awareness of the MB phase out and their willingness to pay for alternatives
11:40 – 12:00	Kristian Moeller (Germany)	Supermarket environmental requirements for fresh agricultural products produced in the European Community
12:00 – 12:20	Luis Miguel Fernandez (Spain)	Commercial policies in Spain that influence grower use of MB
12:20 – 12:40	Sidi Menad Siahmed (UNIDO, Austria)	Use of MB and the development of alternatives in developing countries
12:40 – 13:00	José M. Bolivar (Spain)	Spanish Project on alternatives to MB – the remaining challenges
13:00 – 13:10	Chairs: Maria C. Fernández-Durántez and Alan Dowdy	Summary and conclusions of Economics and Social
	PLENARY 4: WORKSHOP REPORTS Location: **Co-chairs**: José M. Bolivar (Spain) and Mohamed Besri (Morocco)	
13:10 – 13:35	Fernando Romero (Spain)	Workshop Report: Strawberries Audience comment
13:35 – 14:00	Tom Batchelor (Belgium)	Workshop Report: Quarantine & Pre-shipment Audience comment
14:00 – 15:30	**LUNCH** Location:	

FRIDAY 8 MARCH (continued)		
15:30 – 16:05	Vicent Cebolla (Spain)	Workshop Report: Cut-flowers Audience comment
16:05 – 16:30	Antonio Bello (Spain)	Workshop Report: Non Chemical Alternatives Audience comment
	PLENARY 5: CONFERENCE SUMMARY – PANEL DISCUSSION **Co-chairs**: José M. Bolivar and Tom Batchelor	Location:
16:30 – 16:50	John Duniway (USA) Ian Porter (Australia) Fernando Romero (Spain) Julio C. Tello (Spain) David Mueller (USA) Nahum Marban- Mendoza (Mexico) Alfredo Lacasa (Spain) Adam Szczgiel (Poland) Lori Lynch (USA)	Panel Discussion with audience comment
16:50 – 17:00	Tom Batchelor and José M. Bolivar	**CLOSING REMARKS**