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.

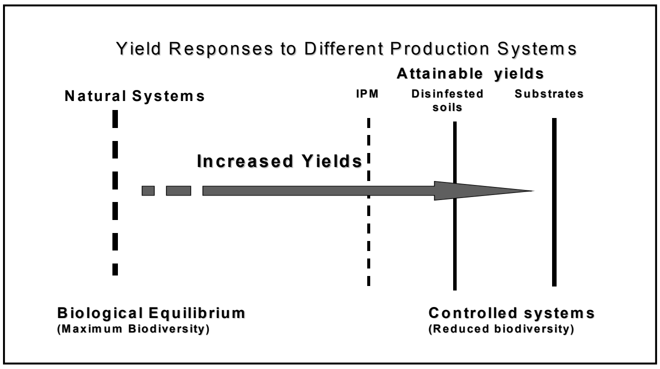

Figure 1: Relationship between plant production systems, crop yields and biodiversity

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

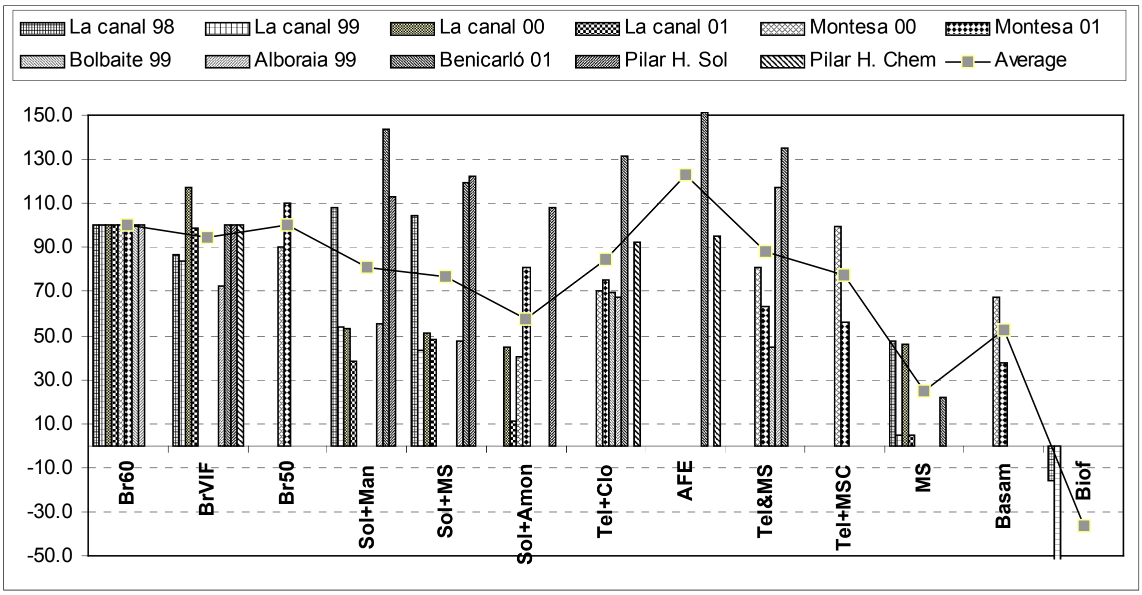
(1). 3rd and 4th years dosage was increased to 72 g/m^2. (2) 1st year applied as ammonium sulphate, 2nd year changed to 35 g/m^2 of Urea as an equivalent N amount.

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.

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



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.

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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