# PROCEEDINGS OF

# INTERNATIONAL CONFERENCE ON

# ALTERNATIVES TO METHYL BROMIDE

## LISBON, PORTUGAL, 27-30 SEPTEMBER 2004

**Title:** Proceedings of International Conference on Alternatives to Methyl Bromide

**Editors:** Tom Batchelor and Flávia Alfarroba

**ISBN:**

**Printed:** European Commission, Brussels, Belgium

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**Editors**

**Tom Batchelor and Flávia Alfarroba**

## ACKNOWLEDGEMENTS

The organisers are very grateful for the hard work and support from the following people, organisations and commercial enterprises:

### CONFERENCE ORGANISATION

Steering Committee: Mr João Gonçalves (Ministry of Environment); Mme Flávia Alfarroba (Ministry of Agriculture); Mr Ricardo Gomes (Ministry of Agriculture); Prof Manuel Belo Moreira (Technical University of Lisbon); Antonieta Castro (Ministry of Environment); Dr Tom Batchelor (European Commission)

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Logistics: Prof Manuel Belo Moreira (Technical University of Lisbon); Mme Antonieta Castro (Ministry of Environment); Mr Luis Morbey (Ministry of Environment); Dr Vidal Abreu (Ministry of Agriculture); Mme Joaquina Fonseca (Ministry of Agriculture)

Alternatives Fair: Mr Ricardo Gomes, Mr Joao Sousa Alves, Mr Jorge Moreira (Ministry of Agriculture); Dr Melanie Miller (Consultant); Prof Manuel Belo Moreira (Technical University of Lisbon)

### MAJOR SPONSORS

Instituto do Ambiente (IA, Ministry of Environment), Direcção-Geral de Protecção das Culturas (DGPC, Ministry of Agriculture), Associação para o Desenvolvimento do Instituto Superior de Agronomia (ADISA, Technical University of Lisbon / Faculty of Agronomy), and the European Commission. We are grateful to Dow AgroSciences for a financial contribution towards the cost of travel that allowed some technical experts to attend this conference.

## IN MEMORIAM

Dr Franco Lamberti died suddenly in his home on 16 August 2004 at the age of 67. He was a highly-regarded nematologist with worldwide experience in taxonomy and crop protection. He collected specimens of nematodes in many countries and prepared excellent keys for their identification.

Dr Lamberti pionereed research and studies on plant nematology in Italy and established the first Italian Plant Nematology Institute, supported by the Italian National Council of Research (CNR), at Bari, Italy in the early 1970s.

His managerial skills were unmatched, as testified by the large number of meetings that he promoted or organised, including workshops and congresses on various aspects of plant nematology.

Dr Lamberti was author of 662 publications including many on alternatives to methyl bromide, covering all the range of nematological research, starting from 1963. He was a fellow of the Society of Nematologists, a founder of the Italian Society of Nematology and was awarded recently the Distinguished Service Award and Special Award of the Organization of the Nematologists of Tropical America.

His expertise and friendship will be missed by all the nematological community. Dr Lamberti is survived by his wife Teresa, daughter Carlotta, son Lamberto, and grandchildren, who receive our condolences.

## FOREWORD

Portugal was pleased to have hosted the "Fifth International Conference on Alternatives to Methyl Bromide". Previous European conferences that were held in Tenerife (1997), Rome (1998), Heraklion (1999) and Sevilla[1] (2002) made important contributions towards Europe's endeavour to phase out methyl bromide, an ozone depleting pesticide. Once in widespread use, a range of alternatives have now largely replaced methyl bromide leaving only 'critical uses' and quarantine and pre-shipment' uses permitted from 1 January 2005.

Agriculture is a very important sector in many countries and especially to those in Europe. Many agricultural producers and food processors are aware of consumer demand for pesticide-free products, and have made efforts to reduce and eliminate pesticides in the food chain and the environment, wherever possible. The phase-out result is beneficial for our long term health and the future health of life on this planet. It is within this context that methyl bromide users in Europe are striving to replace methyl bromide with sustainable alternatives as soon as possible.

The Conference in Lisbon brought together farmers, food processors, researchers, extension workers and industry that have a vested interest in the successful replacement of methyl bromide with viable alternatives. The Conference obtained the best information available on alternatives that are both under development and those already implemented worldwide. In particular, the conference focused on the identification of alternatives for critical uses.

Critical uses are those uses of methyl bromide for which alternatives have yet to be developed, based on strict criteria established by the Parties to the Montreal Protocol and, additionally for Europe, Europe-wide and Member State regulations. The European Community is one of eight Parties that have requested critical uses. The papers presented in this conference by 55 pest and disease control experts from 10 Member States and 7 countries show that a range of alternatives to methyl bromide have been developed recently and, when implemented, could reduce or even eliminate the need for critical uses.

Topics on alternatives to methyl bromide covered in the conference included:

*Keynote papers* that summarised the procedures for critical use exemptions (CUEs) for methyl bromide submitted to, and evaluated by, the Montreal Protocol's technical experts, and the results of their work; the procedures for licensing methyl bromide for CUEs; The impact of European legislation on pesticides including methyl bromide and its alternatives; an update on methyl bromide and ozone depletion; agriculture certification standards; industry-government partnerships for rapid registration of alternatives; technology transfer; and the importance of leadership in eliminating methyl bromide;

*Overview papers* that examined the development and implementation of alternatives in tomato and strawberry crops where most of the methyl bromide is consumed;

*Scientific and commercial papers* that showed the new products under development and the state of play for alternatives that have been on the market for a range of crops for some time. These papers were grouped into sessions on Strawberry production; Cut-flowers and ornamentals; Improved application methods; Quarantine and pre-shipment; Tomato, pepper and other vegetables; Structures, commodities and artifacts; and International standards, technology transfer and adoption of alternatives.

*Alternatives Fair* where companies were invited to display and demonstrate products and equipment on methyl bromide alternatives;

*Alternatives in use* that consisted of summary presented by the co-chairs of each of the sessions;

*Posters* were displayed that supported the presentations made by experts.

[1] Go to Sevilla Conference Proceedings for papers

The Conference was an opportunity for all those involved in developing, implementing and using alternatives to examine the potential for replacing existing MB use, and future methyl bromide CUEs, with alternatives.

This conference showed in many papers and speeches that, based on experience with using the alternatives, the alternatives are as cost-effective as methyl bromide, some less expensive. Innovative technology is now being used to deploy alternatives more effectively in the past in the same way that methyl bromide operations were optimized over the past 40 years of its use. Integrated pest management has always been important, but techniques that rely on this are now becoming more prevalent for replacing methyl bromide with sustainable alternatives.

The spirit to find alternatives is alive and well – they need to be taken up as soon as possible !

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Ministry of Agriculture
Direcção-Geral de Protecção das Culturas

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# SUMMARY OF REPORTS OF THE MEETINGS OF THE PARTIES TO THE MONTREAL PROTOCOL ON EXEMPTIONS FOR THE CRITICAL USES OF METHYL BROMIDE FOR 2005 AND 2006

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## ABSTRACT

In 1992 methyl bromide (MB) was added as controlled substance to the Montreal Protocol. Developed countries must phase out most uses by 1 January 2005, with the possibility of critical use exemptions (CUEs) where alternatives have yet to be implemented. The Parties could not resolve differences in opinion on the amount and time period for the CUEs which led to the scheduling of the first Extraordinary Meeting of the Parties (ExMOP1) in March 2004. ExMOP1 agreed the amount of MB for most of the CUEs for 2005, the level of production necessary to satisfy the CUEs (taking stocks into account), and conditions for granting and reporting on CUEs. Discussions between the Parties will continue on CUEs at the meeting in November 2004 for additional CUEs requested for 2005 as well as CUEs for 2006. The amount of MB finally allocated for CUEs in 2005 will depend for many Parties on the amount that can be licensed, taking into account national regulations on ozone depleting substances and alternatives that have become available since the CUEs were first requested.

**Keywords:** Methyl bromide, Montreal Protocol, critical use exemptions, MBTOC

## INTRODUCTION

In 1994, the Parties to the Montreal Protocol ('the Protocol') agreed to phase out the harmful ozone depleting substance (ODS) methyl bromide (MB) for most of its uses in developed countries on 1 January 2005 (Batchelor 2002). However, ten years later, the Parties could not agree on the appropriate quantity of MB to be used for critical use exemptions (CUEs) after the phase out date. This resulted in, for the first time in the history of the Protocol, the scheduling of an Extraordinary Meeting of the Parties some 4 months later.

The first section of this paper addresses the role of the Meeting of the Parties in the CUE process, the role of the Methyl Bromide Technical Options Committee (MBTOC) and its parent body the Technical and Economical Assessment Panel (TEAP). The second section summarises the results of the First Extraordinary Meeting of the Parties, including the discussions that were held and the decisions that were taken on MB by the Parties. The final section discusses the review of the membership and operations of MBTOC, and comments on the future of CUEs.

## THE CRITICAL USE EXEMPTION PROCESS

### The CUE procedure

The control measures for the phase out of MB were agreed by the Parties in 1994. Countries whose economy is in transition (CEITs) and developed countries needed to reduce their consumption[2] of MB, resulting finally in a 70% reduction on 1 January 2003 and a total phase out of consumption on 1 January 2005 with possible CUEs. The criteria and procedure for determining whether or not a request for a CUE can be recommended to the Parties by MBTOC-TEAP are contained in Protocol Decisions IX/6 and XIII/11 as well as the "Handbook on Critical Use Nominations for Methyl Bromide" ('Handbook', TEAP 2002, 2003). The Parties supplemented these procedures and criteria by agreeing Decision Ex.I/4 at the Extraordinary Meeting of the Parties in March 2004.

[2] *'Consumption' is defined in the Protocol as production plus imports minus exports of controlled substances.*

The current nomination to the Parties for a CUE, the evaluation bodies and the role of the Parties to the Protocol can be described as follows:

1) A Party submits its nomination(s) to the Ozone Secretariat in accordance with the procedure set forth in Decision XIII/11 and the Handbook. The deadline for submissions is 31 January of each year. This enables MBTOC to evaluate nominations and to provide a progress report to TEAP in time for the meeting of the Open-ended Working Group, which is held each year around July;
2) MBTOC categorises the results of its evaluation of each nomination as either 'recommended for approval', 'not recommended for approval' or 'unable to recommend';
3) The Parties review the TEAP report at the Open-Ended Working Group and, on the basis of this review, can propose a Decision for adoption by the Parties at the end of the year. The report is usually considered 'preliminary' as additional information is sometimes sought from the Party when the information is deemed by MBTOC to be insufficient to categorise the application;
4) MBTOC convenes a meeting after the OEWG to consider the comments made by the Parties at the OEWG and to finalise the report based on additional information received by the Parties. A Final Report is prepared by MBTOC for review by TEAP. This report is published before the Meeting of the Parties;
5) The Meeting of the Parties takes decisions on the critical use categories to be granted and the permitted levels of production and concumption of MB necessary to satisfy the CUEs.

**Methyl Bromide Technical Options Committee**

The TEAP is responsible for the tasks specified in Article 6 of the Montreal Protocol in addition to those requested from time to time at Meetings of the Parties. The TEAP analyses and presents technical information. TEAP is the parent body for six Technical Options Committees that mainly document alternatives to ODS for the Parties to the Protocol.

MBTOC was created in 1993 (Andersen & Madhava Sarma 2002). The main task of this Committee is to document each four years the technical feasibility of chemical and non-chemical alternatives and subsitutes for MB. The latest MBTOC Assessment Report was published in 2002. Recently MBTOC has also become responsible for the evaluation of critical use nominations by Parties.

The first evaluation by MBTOC of the CUEs was published in the May 2003 TEAP Progress Report. It was followed by the MBTOC/ TEAP Supplementary Report on Critical Uses (October 2003) published for the consideration of the November 2003 Meeting of the Parties, and the MBTOC/ TEAP 2$^{nd}$ Supplementary Report[3] (February 2004). These reports were discussed at the First Extraordinary Meeting of the Parties. The Supplemental Nominations for consideration at the March 2004 ExMOP submitted recently by Parties requesting CUEs in 2005 and 2006 were published by TEAP (June 2004) and considered by the Parties at the OEWG in June 2004.

**Difficulties related to critical use exemptions**

Since the publication of the first MBTOC report on CUEs several difficulties arose which included:
- The difficulty in the interpretation of 'economic feasibility' in Decision IX/6 as part of determining whether an alternative is '…technically and economically feasible';
- CUEs requested by Parties that in some cases exceeded 30% of a Parties 1991 base level consumption ('phase in instead of phase out') as this is the maximum level of consumption for the two years preceding phase out;

[3] *Nominations in the 2004 round by Parties that also nominated in the 2003 round and by Parties who nominated in 2004 for the first time*

- Unknown stockpiles reported to be large that should be used before MB is produced for CUEs;
- 'Liberal interpretation' of criteria determining the validity of an exemption by MBTOC leading to large CUEs;
- Requests by some Parties for multi-year agreement of CUEs while other Parties regard annual evaluation as important; and
- Perception by developing countries that developed countries are not 'playing by the rules' by requesting large amounts of MB for CUEs when developing countries have made significant progress in the phase out of MB

**THE FIRST EXTRAORDINARY MEETING OF THE PARTIES**

As a result of these difficulties, the Parties agreed to an Extraordinary Meeting of the Parties (ExMOP1) which was held in Montreal from 24 to 26 March 2004.

Extensive consultation between Parties by way of workshops in Brussels and Buenos Aires, and bilateral consultations preceded this meeting. The media, environmental and industrial NGO's and stakeholders kept a close watch on the outcome of these meetings since the meeting in Nairobi had failed to reach an agreement on the issue of critical use exemptions. Dr Klaus Töpfer, Executive Director of the United Nations Environment Programme (UNEP), held bilateral discussions with the Parties to discuss views on CUEs.

During the ExMOP1, some Parties expressed their concern on the large amount of MB being requested for CUEs and that it would affect the integrity of the Protocol. There was no agreement on multi-year exemptions. Nevertheless, after three days of intense negotiations the Parties agreed five decisions. With regard to the critical uses of MB decisions Ex.I/3 and Ex.I/4 are of special importance.

The Parties in Decision Ex.I/3 agreed on the critical use exemptions for MB for 2005. At Mop16 in November 2004 Parties will consider the nominations in the 2004 round (new, additional and deferred CUNs for 2005 and CUNs for 2006). The results are summarized in Table A.

The Parties also agreed on the levels of production and consumption necessary to satisfy critical uses. Parties with a critical use level in excess of the permitted level by the Parties are to make such difference up by using stocks. Parties should also endeavour to allocate the quantities of MB as listed in Table 1. In exceptional circumstances Parties may request reconsideration of approved critical use exemptions.

Furthermore the Parties established conditions for granting and reporting critical use exemptions for MB in Decision Ex.I/4. Most important elements in this decision are the establishment of a Methyl Bromide Alternatives database, development of national management strategies for phase-out of critical uses of MB, and descriptions of the methodology to determine 'economic feasibility'. The Parties hoped that with this decision more fairness, certainty, confidence, practicality, flexibility and transparency would be brought into the evaluation and recommendation process.

Table 1: Critical use exemptions approved and additional for 2005, shown as a percentage of the national consumption of MB in 1991

| Country | Exemptions for 2005 approved at ExMoP1 (tonnes MB) | Additional exemptions requested for 2005 (tonnes MB) | Total potential exemptions for 2005 (tonnes MB) | Percentage of national MB consumption in 1991 (baseline year) |
|---|---|---|---|---|
| Belgium | 47 | 14 | 61 | 20% |
| France | 407 | 95 | 502 | 12% |
| Germany | | 45 | 45 | 55% |
| Greece | 186 | 60 | 246 | 26% |
| Italy | 2.133 | 166 | 2.299 | 33% |
| Poland | | 45 | 45 | 23% |
| Portugal | 50 | | 50 | No data |
| Spain | 1.059 | | 1.059 | 25% |
| UK | 128 | 6 | 134 | 21% |
| **EU-25 total[4]** | **4.010** | **431** | **4.441** | **18%** |
| Australia | 145 | 2 | 147 | 21% |
| Canada | 55 | 7 | 62 | 25% |
| Israel | | 1.123 | 1.123 | 31% |
| Japan | 284 | 464 | 748 | 12% |
| New Zealand | | 95 | 95 | 70% |
| Switzerland | | 9 | 9 | 20% |
| US | 8.942 | 493 | 9.435 | 37% |
| **Total OECD** | **13436** | **2.624** | **16.060** | |

As with other ODSs for which the volumes are agreed as essential or critical use exemptions by the Parties to the Protocol, each Party must now consider the appropriate amount to license for 2005. In this context, the EC is required under Regulation (EC) No 2037/2000 to agree CUE quotas for each category for use from 1 January to 31 December 2005 in each Member State. This is necessary as the Regulation has criteria that are more strict than the Montreal Protocol for determining CUEs.

## REVIEW OF MBTOC AND FUTURE OF THE CRITICAL USE PROCESS

### Review of the working procedures and terms of reference of MBTOC

Decision Ex.I/5 was agreed as the Parties recognized the need to strengthen MBTOC, and to enhance the transparency and efficiency of MBTOC's critical use evaluation procedures. This decision established a process to review the working procedures and terms of reference of MBTOC. An *Ad hoc* Working Group (AHWG) was designated and representatives met immediately prior to the 24th meeting of the Open-ended Working Group (July 2004 Geneva). Although time had been limited for the participants of this meeting, it did however result in consolidated proposals on procedures and terms of reference of MBTOC that were discussed at OEWG. The issue of further guidance had proven to be more difficult. The OEWG decided to reconvene the AHWG prior to MOP16 (November 2004), and Parties were asked to provide inter-sessional comments (especially on further guidance) to assist the work of this group.

### The future of the CUE process

A great deal of attention and energy has recently been put into consultations, discussions and negotiations on MB-CUEs. Although this caused a sensation under the Protocol and fixed everyone's attention on this very succesfull Treaty again, it can only be hoped that this additional attention will further accelerate the end of MB used for CUE's. Both Parties nominating critical uses, and Parties adopting a critical attitude towards these uses, need to build faith in the future of this process. The future will determine if and how fast these nominating Parties will be able to complete the phase out MB.

[4] *This includes the nomination submitted by the Netherlands for 120 kg's.*

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# THE IMPACT OF THE MONTREAL PROTOCOL AND EUROPEAN UNION CONTROLS ON METHYL BROMIDE

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## ABSTRACT

Methyl bromide (MB) is a significant ozone depleting substance that was added to the Montreal Protocol in 1992. European Community Regulation (EC) 2037/2000 on 'Substances that Deplete the Ozone Layer' established more stringent controls on MB than the Protocol such as earlier and greater reductions in MB consumption, a cap on the amount of MB that can be used for quarantine and pre-shipment, minimum qualification requirements for fumigators, and a ban on the sale of MB in disposable cans. MB consumption is scheduled to be phased out in the EC by 1 January 2005 for the vast majority of its uses. After this date, MB can only be imported, produced and placed on the EC market to satisfy those uses agreed to be critical. Requests for critical use exemptions (CUEs) submitted to the Montreal Protocol must also be submitted to the Commission to determine the amount that can be licensed for use in the EC, pursuant to the criteria contained within relevant decisions of the Montreal Protocol and the Regulation. Based on this requirement, Member States have submitted requests to the European Commission for CUEs for 2005. This paper discusses the main criteria and procedures that are being used to determine the amount that should be licensed for CUEs in 2005.

**Keywords:** methyl bromide, Montreal Protocol, alternatives, regulations, critical uses, ozone layer, disinfestations

## INTRODUCTION

The Montreal Protocol on Substances that Deplete the Ozone Layer has at least 170 signatory Parties (countries) and is now widely acclaimed 17 years after its introduction as one of the most successful international environmental treaties. The Protocol establishes phase out schedules to eliminate [5]consumption of harmful ozone depleting substances (ODSs) including methyl bromide (MB) (Anon 2000a). MB, first listed officially as an ODS by the Protocol in 1992, has an ozone depletion potential (ODP) of about [6]0.4 (Anon 1999). Substances which have an ODP greater than 0.1 are normally phased out rapidly; for example, methyl chloroform (ODP 0.12) was scheduled for phase-out by 1996.

The EC reflected in its own legislation the agreements achieved under the Protocol and, moreover, incorporated elements more strict than the Protocol where feasible. Regulation (EC) No. 2037/2000 on 'Substances that Deplete the Ozone Layer' ('the Regulation') entered into force on 1 October 2000. The Regulation now applies to 25 MSs including those[7] that joined the European Union on 1 May 2004.

The first section in this paper discusses Protocol agreements on MB for developed and developing countries, and related EC legislation pertaining to agricultural uses of MB consumed for quarantine and pre-shipment (QPS) and non-QPS uses. The final section discusses the impact of the Montreal Protocol and the Regulation on the use of MB for critical use exemptions (CUEs) from 1 January 2005.

## CONTROLS ON METHYL BROMIDE

5 'Consumption' is defined as 'Production + Imports – Exports' which in effect controls the reduced amount of MB that can be placed on the market each year, relative to the consumption in each country in 1991.

6 All ODPs are relative to CFC-11 which has an ozone depletion of 1.0. The vast majority of CFC production was banned in developed countries in 1994.

7 Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia

## Montreal Protocol

### Developed countries

Under the Protocol, governments around the world have agreed a MB phase-out schedule for developed countries (including most countries with economies in transition, CEITs) consisting of a 25% reduction in consumption in 1999 relative to 1991 levels, a 50% reduction in 2001, a 70% reduction in 2003 and a total phase out of consumption by 1 January 2005 with possible critical use exemptions. Developed countries are permitted to produce MB to meet the Basic Domestic Needs of developing countries based on Protocol agreements that take into account the declining MB requirements in developing countries.

The amount of MB consumed for quarantine and pre-shipment [8](QPS) applications was excluded from control as the Parties in 1992 considered MB to be important for rapid disinfestation of a small, but highly-valued, proportion of international food trade. It was also considered important to avoid new non-tariff trade barriers at a time when such trade was likely to increase in developing countries.

### Developing countries

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

To assist developing countries to meet their MB commitments in the Montreal Protocol, the Protocol's Multilateral Fund has provided funds of about $60 million for demonstration and investment projects in more than 55 developing countries. On the basis of progress in the adoption of alternatives to MB, some developing countries have accelerated their national phase out schedule to avoid further dependency on MB and potential consumer boycotts of MB-treated commodities in developed countries. Examples of developing countries which plan to phase out major uses of MB by 2007 include Morocco, Jordan and Turkey.

In the light of such progress by developing countries, the Parties to the Protocol agreed to review in 2003 the developing country MB control measure. The Protocol's Technology and Economic Assessment Panel (TEAP) April 2002 summarised developing country progress in alternatives which provided a useful basis for the review. In 2004, the Parties to the Montreal Protocol will consider three additional interim reduction steps, between 2005 and 2015 as there was no agreement by the Parties in 2003 to a revision of the control measure. The reasons for the lack of agreement are provided by Hildebrand (2004).

### European Community

Articles 3 (production) and 4 (placing on the market) in the Regulation contain the most information pertaining to MB. In general, the regulation requires the Member States to take earlier and slightly larger reduction steps in MB consumption compared to the Protocol. Moreover, the EC became the first Party to place a limit on the amount of MB that could be used for QPS purposes. The Commission, in consultation with MSs, is required to encourage the development and use of MB alternatives as soon as possible. Examples of activities to date include EC-funded research projects and co-funding of several international conferences on MB alternatives.

In other articles of the Regulation applicable to MB, Article 16 bans MB placed on the EC market in disposable containers. Article 17 requires MSs to have in place qualification requirements for fumigators and to define the minimum qualification requirements for personnel involved in MB installations and operations. All precautionary measures practicable must be taken to prevent and

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

minimise leakage of MB from fumigation installations and operations in which MB is used. When MB is used in soil fumigation, it is mandatory to use virtually impermeable film (VIF) for a sufficient period, or other techniques which ensure at least the same level of environmental protection.

**QPS controls**

The Regulation capped the use of MB for QPS the amount of MB that was placed on the market (imported and produced) in the period 1996–1998. Commencing in 2002, MSs have reported to the Commission annually on the quantities of MB authorised for QPS in their territory in the previous year, the purposes for which it was used and progress in evaluating and using alternatives for QPS. The Regulation aims to ensure that MB consumption for QPS is reduced over time as alternatives are developed.

In an emergency, if unexpected outbreaks of particular pests or diseases so require, the Commission, at the request of the competent authority of a MS, may authorise the temporary use of MB. Such authorisation may be for 120 days or less and cannot exceed 20 tonnes.

*Critical uses*

Article 3(2)(ii) of the Regulation states that,

> "*In the light of the proposals made by Member States, the Commission shall, in accordance with the procedure referred to in Article 18(2), apply the criteria set out in Decision IX/6 of the Parties, together with any other relevant criteria agreed by the Parties, in order to determine every year any critical uses for which the production, importation and use of methyl bromide may be permitted in the Community after 31 December 2004, the quantities and uses to be permitted and those users who may take advantage of the critical exemption. Such production and importation shall be allowed only if no adequate alternatives or recycled or reclaimed methyl bromide is available from any of the Parties*".

Any request for critical uses of MB is therefore evaluated firstly in the Montreal Protocol and secondly by the Commission / Management Committee. Each evaluation is for different reasons. The Montreal Protocol in effect determines the maximum amount that can be produced or imported by the nominating Party, whereas the amount agreed by the Management Committee determines the amount that can be licensed according to Article 3(2)(ii). These procedures are consistent with those used for licensing CFCs for essential uses for metered-dose inhalers that follow Decision IV/25 in the Montreal Protocol and Article 3(1) of the Regulation.

There are several criteria in the italicised text above which are important when considering that amount of MB that can be licensed for CUEs in the EC in 2005:

<u>Proposal by Member States to the European Commission</u>: Agreement in the Montreal Protocol to a volume of MB being eligible for CUEs in 2005 by amount, category and MS e.g. 300 tonnes for flour mills in the UK, becomes in itself the maximum amount that can be agreed under the Regulation to be placed on the EC market, by import or production, for that purpose for the period 1 January – 31 December 2005. Currently, 10 MSs have applied to the Commission for MB for CUEs for this period (see Hildebrand 2004 for details).

The Commission has commissioned a report by a team of experts to analyse the CUE requests and to advise if the amount of MB requested complies with the criteria contained within the Montreal Protocol and the Regulation.

<u>Procedure referred to in Article 18(2):</u> Article 18 refers to a Management Committee which is chaired by the Commission and which aims to promote the implementation of the Regulation. The members of this Committee are experts from the MSs, usually from environment departments. Article 18(2) refers to specific procedures that can be used by the Committee in reaching a decision, including the use of qualified majority voting.

<u>Apply the criteria set out in Decision IX/6:</u> This Decision was agreed by the Parties in 1997 and is the main decision that contains criteria for determining whether MB requested should be recommended for a CUE. In making any application to the Commission, Member States are requested to pay particular attention to the criteria contained in Decision IX/6. The use of MB bromide should only be considered "critical" if the MS determines that:

(i) “The specific use is critical because the lack of availability of MB for that use would result in a significant market disruption;

(ii) There are no technically and economically feasible alternatives or substitutes available to the user that are acceptable from the standpoint of environment and health and are suitable to the crops and circumstances of the nomination;

(iii) All technically and economically feasible steps have been taken to minimise the critical use and any associated emission of MB; and

(iv) It is demonstrated that an appropriate effort is being made to evaluate, commercialise and secure national regulatory approval of alternatives and substitutes, … and that research programmes are in place to develop and deploy alternatives and substitutes….

(v) MB is not available in sufficient quantity and quality from existing stocks of banked or recycled MB.”

Decision IX/6 makes it clear that it is the nominating Party that is responsible for ensuring compliance with criterion (i) above. Each Member State is therefore required to support its view that the specific use is critical because the lack of availability of MB for that use would result in a significant market disruption.

The Regulation makes specific reference to the criteria in Decision IX/6 in order to ensure that any MB placed on the market for CUEs takes this decision into account immediately prior to licensing. This is important as many of the applications to the Parties for CUEs were based on evidence of a lack of MB some 2-3 years earlier and hence the need for a ‘final check’ to ensure that any recently developed alternatives have been taken into account, leaving MB to be licensed only for those uses that are consistent with Decision IX/6.

<u>The quantities and uses to be permitted:</u> The Management Committee decided that the fumigators should be assigned quotas of MB for CUEs as Article 17 requires MSs to have in place qualification requirements for MB fumigators in the EC. For the past three years, the import, export and production of ozone depleting substances in general has been managed using an ODS website. This website allows the European Commission to issue a licence only to those with a valid quota and a use compliant with the Regulation.

There are currently more that 200 enterprises who have a password access to debit a quota registered on the ODS website. All quotas on the website have been agreed for each enterprise and substance following the procedures of Article 18, that is, by the Commission assisted by the Management Committee.

Similarly, the fumigators would be assigned a quota by MS and category of critical use. Each fumigator assigned a quota would enter the website to request a licence to have MB imported, produced or used from stock for their particular CUEs to which they have been assigned in 2005. The quota assigned to each fumigator will depend on the outcome of the meeting of the Management Committee and the relative market share per category of use provided to the Commission by the relevant MS competent authority.

Once assigned a quota, a fumigator would be able to transfer all or a portion of the quota to another fumigator within the same category of use, provided there is agreement of both fumigators concerned and the relevant MS competent authority. A quota transfer is permitted in such cases when a fumigator may not be able to use their assigned CUE quota.

<u>Stocks of MB:</u> Pursuant to Decision IX/6(1)(b)(ii), the European Community is only able to allow the import or production of MB for critical uses if it is not available in sufficient quantity and quality from existing stocks of banked MB, and under Article 3(3)(ii) of the Regulation, from ‘….recycled or reclaimed MB from any of the Parties’.

Pursuant to Article 20 paragraphs 1 and 3 of the Regulation, each MS has been requested to report on the quantity of MB available within its territory for all intended uses[9] on or about 1 November 2004 that is likely to be carried over to 2005. This period is likely to be reliable for assessing available MB

[9] Critical and non-critical but excluding feedstock, BDN, IPR, laboratory and quarantine and pre-shipment uses

stocks as it is unlikely to be used significantly in the cooler winter months of November and December in Europe. Nil returns are required in cases where MB is unlikely to be available as it has been banned for all intended uses[3]. MSs must ensure that all quantities for the intended uses[3] are accounted for, particularly those that could be stored in locations where MB has been used in the past such as, for example, in locations used by producers, importers, fumigation companies, fumigators, farmers and mill owners.

The Commission / Management Committee will be meeting in October and December to agree quotas for CUEs. As a result of the decision taken on critical uses a Commission Decision will be published in 2005. Fumigators are expected to be able to request a licence on the ODS website in early January 2005 for any uses of MB agreed by the Management Committee to be critical.

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## UPDATE ON THE REVIEW OF PESTICIDES IN THE EUROPEAN UNION AND IMPLICATIONS FOR METHYL BROMIDE AND CHEMICAL ALTERNATIVES

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### ABSTRACT

Council Directive 91/414 EEC states that active substances cannot be used in plant protection products unless they are included in a positive European Union list. An EU programme of evaluation to create this list is underway. Most of the active substances under evaluation are pesticides but many - such as growth regulators, pheromones etc - are not. All plant protection uses are covered and not just those in agriculture. Pesticides used in other areas, for example as veterinary drugs or as biocides, are covered by other legislation. Once a substance is included in the positive list, Member States may authorise the use of products containing them.

The following are not considered plants, parts of plants, or plant products and therefore they are not required to be considered by the Directive: Steam or hot air treatments; solarisation; grafted plants, use of resistant rootstock; crop rotation; cultural practices; substrates, soil-less cultivation; heat treatments; cold / freezing treatments; aeration of grain; hermetic storage; pressure or vacuum treatments; reduced levels of oxygen or increased levels of carbon dioxide.

Progress in the evaluation of the dossiers is given in the presentation for a number of alternatives to methyl bromide including 1,3-dichloropropene, metam sodium, etridiazole sodium tetrathiocarbonate, sulfuryl fluoride, phenamiphos, chloropicrin, malathion, cadusafos, pirimiphos- methyl, oxamyl, deltamethrin, carbofuran, and propamocarbe.

Guidance Documents - for the implementation of Council Directive 91/414/EEC (Plant Protection Products) can be found on
www.europa.eu.int/comm/food/plant/protection/resources/publications_en.htm
Other documents on the internet include http://europa.eu.int/comm/food/plant/protection/index_en.htm. For substances status: Doc. 3010; For general status : “State of the Works” (Rev. 66); For background : Report to Council and Parliament.

# STRAWBERRY FRUIT PRODUCTION: SUMMARIES OF ALTERNATIVES TO METHYL BROMIDE FUMIGATION AND TRIALS IN DIFFERENT GEOGRAPHIC REGIONS

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## ABSTRACT

Strawberry yields have risen by about 300% since the 1940's due to improved varieties, virus elimination through certification schemes and the use of methyl bromide (MB) for soil disinfestation. Strawberry breeders focused on yield at the expense of disease resistance which explains the reason that strawberry varieties grown today are highly susceptible to soil-borne pathogens and highly dependent on soil disinfestation. The international ban on the use of MB after 2005 for soil disinfestation in developed countries has resulted in over 100 research trials worldwide commissioned in the last 10 years to search for non-chemical and chemical alternatives. So far, the most effective alternatives are 1,3-dichloropropene mixed with chloropicrin (PIC, 65:35); and drip-applied, emulsifiable formulations of either chloropicrin alone or 1,3 D/PIC; combined with or without follow up treatments with metham sodium. Methyl iodide, ethanedintrile, and propylene oxide show promise. Strawberry production in hydroponic substrate systems in greenhouses is suitable for supplying niche markets or for production in cool climates with short cropping cycles. Solarisation is a good alternative in some circumstances. Varieties resistant to some pests but not others limit widespread use of this technique. Soilless cultivation produces high yields due to the double cropping system but currently this method produces only 5% of the world's strawberries. IPM systems produce 20-30% of the world's strawberries but IPM systems are knowledge intensive and in themselves not a direct replacement for MB. The requirement to phase-out MB has been a unique opportunity for the strawberry industry to critically examine the sustainability of its production system. The strawberry industry should consider switching to the next best fumigant alternative, develop IPM systems, or invest in the development of alternative soilless production systems for industry and environmental sustainability.

**Keywords**: methyl bromide, strawberry fruit, methyl bromide, alternatives, 1,3-dichloropropene, chloropicrin, ethanedintrile, propylene oxide, metham sodium, Montreal Protocol

## INTRODUCTION

Yields of the modern strawberry have risen by around 300% since the 1940's due to improved varieties, virus elimination through certification schemes and the use of methyl bromide (MB) for soil disinfestation. The widespread use of MB in the industry has also enabled breeders to focus on yield as a major determinant for selection, resulting in the development of extremely high yielding strawberry varieties (Duniway 2002a). This, however, has been at the expense of development of plants with a high level of disease resistance, so as a consequence several recently bred strawberry varieties are highly susceptible to soil-borne pathogens and highly dependent on soil disinfestation (Browne *et al.* 2003; Martin, 2000). Effective soil disinfestation is also critical to the production of high quality certified planting material for the fruit industry.

The announcement that MB was an ozone-depleter and listed for phase-out under the *Montreal Protocol* in 1992 alarmed strawberry industries around the world because it challenged the very nature of their production systems. Without a suitable replacement for MB, it was reported that strawberry industries would suffer between 35% to 52% yield loss in Australia and USA respectively (Porter and Mattner 2001, 2002; Shaw & Larson 1999). For this reason, research on alternatives to MB has been more vigorous in the strawberry industry than for any other crop affected by the phase-out. Whilst the impending ban on MB represents the greatest challenge to the strawberry industry in the modern era, in other ways it has been a 'godsend' because it has forced industries to critically examine the sustainability of their production systems.

This paper discusses the effect of the *Montreal Protocol* on use of MB. It documents the approaches that strawberry industries have taken to phase-out MB and the issues that have driven change in strawberry production systems.

## INTERNATIONAL REGULATIONS ON METHYL BROMIDE

Continued use of MB after 2005 through a specific Critical Use Exemption (CUE) is only available to industries which justify to the Parties of the Montreal Protocol that the specific use is critical because it complies with the criteria of Montreal Protocol Decision IX/6 and other relevant Decisions (see Hildebrand 2004 for details).

In spite of several alternatives being available to replace MB in many production regions, several major strawberry fruit industries have applied for CUEs mainly because they consider that the alternative is not fully effective or available due to environmental restrictions such as township caps, buffer zones and porous soil types, and time is needed for commercial phase up of alternatives. In some instances, industries are being required to restructure cropping practice to ensure market windows are maintained by improving application methods for alternatives, and giving consideration to longer plantback times and altered crop performance when using different alternatives.

The international strawberry fruit industry has applied for approximately 3000t of MB for CUEs in 2006. This is the second largest request in total for CUE's by a particular industry. In order to comply with emissions reduction mandated under Decision IX/6, CUE recipients should use impermeable films (eg. VIF) and/or lower rates of MB in MB/PIC formulations and consider less frequent fumigation with MB.

## ALTERNATIVES TO METHYL BROMIDE

The suitability of alternatives to MB has been reviewed comprehensively by the Methyl Bromide Technical Options Committee (Anon 2002) and also by other authors in many other countries (Ajwa *et al.* 2004; Duniway 2002a and b; Martin & Bull 2002; Porter & Mattner 2002). The major chemical and non-chemical alternatives adopted or considered for adoption to replace MB are shown in Table 1.

TABLE 1: Main alternatives to methyl bromide being implemented or considered for use by the strawberry fruit industry.

| **1. In-kind chemical alternatives** | **Main issues which may affect adoption[#]** |
|---|---|
| 1,3-D/chloropicrin | • More precise application requirements than MB; New drip application methods for EC formulations; Longer plantback under most conditions |
| 1,3-D EC followed by metham sodium | • Combination treatment applied by drip irrigation sequentially about a week apart |
| Chloropicrin alone | • Both injected and EC formulations effective; Odour and buffer zones are a critical issue in some countries eg. Israel |
| Metham combined with chloropicrin | • Effective, but application presently difficult as can't be mixed; Longer plantback than MB |
| Methyl Iodide | • Effective, first registration pending in US; Cost may be prohibitive, therefore mixtures with PIC (30:70) should be considered as a means to reduce cost |
| Dazomet | • Application conditions critical as good moisture required for effectiveness; Could be applied in bands to reduce cost; Longer plantback than MB |
| Cyanogen, sodium azide, propylene oxide, dimethyldisulphide | • Some early results promising especially for weed control with the first two products; All products require further development |
| **1.In-kind non chemical alternatives** | |
| Solarisation | • Only suitable where treatment can be applied during warm (>35°C) climates, ie. suit crop rotation |
| Steaming | • At present impractical and costly for open field application |
| **2.Methods which avoid the need for disinfestation** | |
| Resistant varieties | • Some conventional varieties have specific pathogen tolerance |
| Hydroponics/ soilless substrates | • Effective in cool regions, cost effectiveness questioned in temperate climates |
| **3. Other alternatives** | |
| IPM, Crop rotation, Organic amendments, Biofumigation, Biologicals, Propane burners for weed control | • Generally these techniques are used to improve management of crops, but are not yet considered in-kind replacements to MB. |

# - Buffer zones and other local regulatory issues affect the uptake of any fumigant alternatives

## CHEMICAL ALTERNATIVES

During the last 5 years, over 100 studies worldwide have been conducted on alternatives in major strawberry fruit production areas. A sample of these trial results reported at the International Methyl Bromide Alternative Outreach Conferences in the USA (Table 2) have demonstrated that at least three chemical alternatives are giving yields equivalent to MB, and that these trends are consistent across different regions of the world.

TABLE 2. Average comparative performance of chemical alternatives relative to methyl bromide for yields of strawberry fruit (Data taken from MBAO studies 1999 to 2003)

| Treatments | MB/Pic | Unt | TC35 | Pic | MS | MI | MS &Pic | Daz | Pic EC | Inline | Inline & Pic | Inline & MS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1. USA* | | | | | | | | | | | | |
| No. of studies | 43 | 40 | 29 | 16 | 22 | 18 | ND | 6 | 5 | 5 | 6 | ND |
| Relative yield | 100 | 68 | 101 | 98 | 82 | 101 | 94 | 98 | 104 | 108 | 92 | 101 |
| *2. Spain* | | | | | | | | | | | | |
| No. of studies | 16 | 8 | 16 | 8 | 4 | ND | ND | 10 | ND | ND | ND | ND |
| Relative yield | 100 | 78 | 103 | 104 | 80 | | | 96 | | | | |
| *3. Australia* | | | | | | | | | | | | |
| No of studies | 11 | 11 | 5 | 3 | 3 | ND | 3 | 2 | ND | ND | ND | ND |
| Relative yield | 100 | 84 | 123 | 101 | 97 | | 101 | 101 | | | | |

MB/Pic = Methyl bromide/chloropicrin; TC35 = 1,3 D/chloropicrin (Telone C35); Pic = chloropicrin alone; MI = Methyl iodide; MS and Pic = Metham sodium followed by chloropicrin; Daz = Dazomet granules; PIC EC = emulsifiable concentrate of chloropicrin: In Line = drip applied emulsifiable concentrates of 1,3 D combined as indicated with chloropicrin or metham sodium. ND = No Determination

Whilst these data have not been subjected to a full meta-analysis, they demonstrate the broad spectrum control of diseases that can be achieved with combinations of different fumigants. For example, one fumigant mixture, 1,3-D/Pic (Telone C-35), whether injected into soils or drip applied, has been consistently effective across major production regions in USA, Spain and Australia. In all three countries, the product has already been successfully adopted for a substantial proportion (>20%) of strawberry fruit production in each country. It has been so successful in Australia that no application for a CUE was made for use in 2006.

Other alternatives have also given similar results to MB, eg. PIC applied alone or combined with metham, methyl iodide and Telone C-35 'In Line' followed by metham sodium. Several new products have also given promising results in recent trials, eg. ethanedinitrile and sodium azide (Mattner *et al.* 2003; Norton 2003). Identification of the conditions for applying and optimising the movement of other fumigant chemicals through soils is a key to their further successful and rapid adoption. Industries also need assurance that the alternatives will perform consistently from year to year in different soil types eg, plantback times for some alternatives have been inconsistent (Table 3).

TABLE 3: Plant back times recommended and observed in field trials in Australia

| Fumigant | Recommended Plant back | Plant back determined in field tria |
|---|---|---|
| MB (70:30, 50:50, 30:70) | 3 weeks | 2 weeks |
| Chloropicrin | 3 weeks | 2-3weeks |
| Dazomet | 2-4.5 weeks | 2-12 weeks |
| Metham sodium | 2-3 weeks | 2-8 weeks |
| Telone C35 | 2 weeks | 2-6 weeks |

## NON CHEMICAL ALTERNATIVES

***Solarisation and steaming:*** 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 effectiveness in other regions, eg. Huelva, Spain (Batchelor 2000, Lopez-Aranda *et al.* 2000, Romero 2000). Solarisation is up to 80% cheaper to apply than MB 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 prevent open field use on a large scale. Recent advances in mobile machines (e.g. Celli Pty Ltd, Italy) may improve the adoption of this technique.

***Resistant varieties:*** Development of resistant varieties as an alternative to MB has been difficult to attain due to the need for durable resistance to the wide range of major pathogens affecting strawberries. Recent studies have shown vastly different levels of tolerance to *Phytophthora* spp. and *Pythium* spp. in existing and newly released varieties in the US (Browne *et al.* 2001). The cultivars, 'Aromas', 'Camarosa' and 'Pacific' generally offered much better tolerance to *Phytophthora* than 'Diamante', 'Gaviota', 'Pajaro' and 'Selva' (Martin 2000).

***Soilless culture/hydroponics:*** As market pressures against use of harmful pesticides increase, more and more strawberries will be produced in substrates under hydroponics. Currently, only a small proportion (<5%) of the world's strawberries are produced this way, and usually for crops that fetch high prices (early season, niche markets). Holland, Japan, Italy, New Zealand, UK and China are some of the key producers of hydroponic strawberries. Scotland produces 28 ha (7% of total production) of strawberry fruit in substrate systems (Batchelor 2000). These substrate systems produce 46% more fruit per year than crops in MB treated soil, because growers are able to 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. Efforts to reduce initial set up costs for substrate systems will increase their adoption as an alternative to MB worldwide.

***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). Although many of these methods are not a direct replacement for MB, knowledge of how to optimise their use for strawberry crops can dramatically improve pest and disease control and yields (Bull *et al.* 2002; Mattner *et al.* 2004).

## FUTURE CHALLENGES AND BENEFITS OF THE METHYL BROMIDE PHASE OUT

In 1995, the phase out of MB threatened production of strawberry fruit in several major production areas worldwide, however research and development of new strategies since then have ensured that the majority of strawberry fruit production is no longer threatened. With less than one season left to adopt alternatives to MB on farm, growers should already have considered commercial scale up of at least one alternative to MB to ensure viability and future sustainability.

The strawberry fruit and runner industries should not be complacent and rely on CUEs being available for substantial periods after 2005. Even though some CUE's have been agreed by the Parties the MB requested has yet to be licensed by the national authorities. Moreover, future markets are demanding more 'environmentally friendly' production practices and no industry will be truly sustainable until such practices are implemented. The strawberry industry has three options; it can switch to the next best fumigant alternative, develop integrated crop management systems based largely on varieties with greater resistance to disease or invest in the development of alternative soilless production systems which enable soil and environmental sustainability. Whichever strategy, the industry needs to develop a greater understanding of the chemical and biological factors which maximise crop yield and place less reliance on chemical fumigants to support the industry. Is the industry ready and if not, can it afford to wait?

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# MAIN RESULTS OF TRIALS ON METHYL BROMIDE ALTERNATIVES FOR STRAWBERRY FRUIT AND RUNNERS PRODUCED IN SPAIN

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## ABSTRACT

A project was initiated in 1997 in Spain to find alternatives to methyl bromide (MB) for use in both high-elevation nurseries and strawberry fruit production. In nurseries, all the fumigants reduced quantitatively the soil fungal populations, but only MB:PIC, and Dazomet caused a clear reduction in the fungal genera composition. However, the inconsistency of weed levels and yield results are problems that remain to be solved to find alternatives to MB. In strawberry fruit production, several fumigant alternatives applied under VIF films could be appropriate short and medium-term alternatives to MB when applied under low pressure nematode populations. However, some of them are not registered yet in EU and/or Spain, and their environmental impact must be carefully studied. Furthermore, EU policy on future agrochemical use (including 1,3-D and/or chloropicrin) is uncertain. For these reasons and others, Spain and other important strawberry producer countries worldwide have applied for critical use exemptions for the use of MB in 2005.

**Keywords:** new chemicals, nurseries, fruit production, critical uses.

## RUNNER PRODUCTION (STRAWBERRY NURSERIES)

Finding technically and economically feasible alternatives to methyl bromide (MB) for strawberry nurseries is a difficult task. Despite of this fact, research funds have not been forthcoming to solve this problem. Official research projects involved on MB alternatives for strawberry nurseries only exist in United States (California) and Spain. However, many developed countries have applied for Critical Use Exemptions (CUEs) for the use of MB from 1 January 2005: Australia (35.7 t), Belgium (3.4 t), France (40.0 t), Canada (79.5 t), Israel (140 t strawberry plus nursery), Italy (100 t), Spain (230 t) and United States (55 t). These CUE exemplify the difficulty globally in finding alternatives.

In the case of the Spanish high-elevation strawberry nurseries (around 1,150 ha and more than 600 million plants), several key points should be considered:

a) The requirement to comply with strict plant health production standards in order to comply with a special regulatory system (EU and national regulations on certification and control of strawberry plants);
b) Intensive international-national traffic of mother and commercial runner plants;
c) The particular agro-environmental surroundings of nurseries: Fumigants are applied in the winter in March; relocation of nurseries to minimize soil stress and soil-borne pathogen contaminations; and current production success of the nursery with the previous type of crops planted in the nursery e.g., cereals, vegetables, fallow.

These particular conditions have the following consequences:

a) The effectiveness of the soil fumigation is dependent on the weather conditions (soil temperature and humidity);
b) The cycle of cultivation (April-October) makes it difficult to use non-chemical MB alternatives due to the long plant-back time (time between fumigation and planting), even for chemical

alternatives. If the nurserymen try to apply physical (soil solarization) or chemical alternatives in the previous summer (July-August), these 7-8 months delay in plant-back time result in uneconomic cultivation and involve a risk of soil-borne pathogens re-contamination, weeds in particular. Moreover, plastic film used for soil solarization in the area of Castilla-Leon (Northern Central Spain) has a 95% of damage from violent hail storms during July and August.

Due to the international phase out of MB, a specific project was initiated in 1998 to find short-term, technically and economically feasible alternatives to MB for strawberry nurseries. This project was designed to determine the efficacy of chemical alternatives compared to the standard used in strawberry nurseries MB:PIC (400 kg/ha) when applied in the same general conditions. Experiments with a randomized block design with 3-4 replications in large scale plots were carried out in two locations: Arévalo-Vinaderos (Avila) and Navalmanzano (Segovia). A brief description of the treatments is shown in Table 1. From 2003, a demonstration programme was initiated at Avila (Cabezas de Alambre) and Segovia (Navalmanzano-Mudrián). MB alternatives for strawberry nurseries are required to solve three problems: a) soil-borne pathogens (fungi and nematodes) control; b) weeds; c) Consistent yield of commercial runner plants.

In terms of the results, nematodes were abundant in all locations. In Navalmanzano (Segovia), populations consisted of Rhabditidae, Dorilaimidae non parasitics, Mononquidae and a low proportion of Tilenquidae from diverse genera *(Aphelenchus* spp., *Scincura* spp., *Tylenchus* spp., *Tylenchorhynchus* spp., *Pratylenchus* spp., *Neotylenchus* spp.), none of them parasitic on strawberry. In Arévalo-Vinaderos (Avila), the populations were consistent with the previous cereal cultivation: *Pratylenchus zeae*, *Heterodera avenae, Punctodera* spp., besides other Tilenquidae and Rhabditidae. Also in this location, no strawberry parasites were detected. All the chemical treatments did reduce nematode populations.

In relation to the soil-borne fungal pathogens, a summary of our results (1999-2002) was presented recently (De Cal *et al.* 2004a) and a poster prepared showing the effects of chemical alternatives on soil-borne diseases in our experiments (1999-2003) (De Cal et al., 2004b). In summary, Verticillium wilt (caused by *Verticillium* spp.) and crown rot (caused by *Phytophthora cactorum*) were the main diseases. Chloropicrin (pic), 1,3D-PIC (Telopic$^{TM}$) and Dazomet (Basamid$^{TM}$) compared well with MB fumigation for control of strawberry nursery diseases. All the fumigants reduced quantitatively the soil fungal, but only MB:PIC, and Dazomet caused a clear reduction in the fungal genera composition**.**

Weed control experiments commenced in 2002 and were previously reported (Melgarejo *et al* 2003). The results of chemical alternatives on weed control obtained in our 2003 experiments and demonstrations were presented elsewhere (García-Méndez *et al.* 2004). In summary, results obtained on weed control in 2002 were very inconsistent. The results of the 2003 experiments, however, showed that Telopic$^{TM}$, Metam Sodium (MS) + PIC, and Dazomet were equivalent to MB:PIC. This contrasted with the 2003 field demonstrations that showed MB:PIC was better than other herbicides. The most recent 2004 observations undertaken on experiments and field demonstrations could reverse these results again. Inconsistent weed control is a problem that remains to be solved.

The yields (commercial runner plants harvested/m$^2$) obtained as a result of different trials are presented in Table 1. Yields from alternative treatments produced inconsistent results between locations and years. Moreover, yield results obtained in large scale demonstration trials started in 2003 to facilitate the transfer of the most promising alternatives also showed inconsistent results (Table 2). In contrast, standard MB:PIC (50:50, 400 kg/ha) gave consistent results between locations and years.

## STRAWBERRY FRUIT PRODUCTION

The strawberry fruit production in Spain is located in Huelva area (6,500 ha and 270,000 t have been estimated for 2003). A specific project to find short-term technically and economically feasible alternatives to MB was initiated in 1997 (Project INIA). A description of MB alternatives research on strawberry fruit in the USA, Spain, Italy and other Mediterranean countries was published recently (Ajwa *et al.* 2003).

From 1997/98 to 2000/01, field scale experiments were performed on two farms in Huelva. More than 25 alternative treatments were considered. Annual cv. 'Camarosa' production under small tunnels was monitored. Soil treatments were ranked into four groups of MB alternatives according to their decreasing efficiency: 1º) 1,3-D:PIC (61-35) (Telopic$^{TM}$), 2º) MB:PIC (67-33) or (50-50); PIC alone; Solarization + MB; Dazomet, 3º) Solarization + MS; MS alone, and 4º) Solarization + biofumigation; biofumigation alone; solarization alone; electromagnetic fields; and untreated controls (López-Medina *et al.* 2003, Medina *et al.* 2004). From 2001/02 to 2003/04, field scale demonstrations were performed in five (2001/02) and two (2002/03 and 2003/04) farms, respectively. Cv. 'Camarosa' was cultivated under large plastic tunnels in each farm. Results showed that the agronomic response to 1,3-D:PIC (61-35) was similar to that obtained with MB:PIC (50-50), even with 50-55% dosage under black VIF film. Yield obtained with Dazomet was not consistent all along the three-year period. In the case of Sol.+Biof. and Sol.+MS (2001/02), the control of *Pratylenchus penetrans* nematode populations and yield were poorer than in the MB:PIC and Telopic$^{TM}$ treatments (Medina *et al.* 2004). Results from 2003/04 field scale demonstrations showed promising results with Propylene Oxide (PPO, Propozone$^{TM}$) soil treatments.

In 2002/03 and 2003/04 a new series of experiments were initiated at two locations. On each orchard: "Occifresa" (Moguer) and "Cumbres Malvinas" (Palos de la Frontera), a complete randomized block design with 3 replications (78 $m^2$/rep.) and 10 fumigant treatments was used. Treatments can be categorized into three groups: a) new chemical alternatives; b) implemented alternatives with VIF films and reduced dosage to 50-65% of standard; and c) new mixtures with chloropicrin (Table 3). Fumigations were conducted on September 26-27, 2002, and mid-September, 2003. Cv. 'Camarosa' was cultivated under large plastic tunnels in each farm. Planting was carried out in mid-October 2002 and 2003.

Populations of *P. penetrans* nematodes in location 1 ("Occifresa"), and *Meloidogyne hapla* in location 2 "Cumbres Malvinas" were detected every year. The tesults of the control of these populations are given in Table 4. Despite of the presence of soil-borne pathogens yields were optimal in both locations and years (Table 5). Our results showed that VIF film applications improved the performance of chemical alternatives. In this case, increased dosage from 50% to 65-70% of the standard applied under polyethylene (LDPE) films and mixtures of chemical fumigants (DMDS$^{TM}$ and MS) with PIC yielded significantly better results.

PPO gave promising yield under VIF shank-application. However, its capacity to control *P. penetrans* populations was very weak. Yields with calcium cyanamide were unacceptably low probably due to losses of the fumigant due to excessive irrigation and soil leaching when applied. As in the previous years of experiments and demonstrations, average yield and fruit weight obtained with Telopic$^{TM}$ and PIC alone were satisfactory. However, PIC alone resulted in very weak control *P. penetrans*.

## CONCLUSIONS

After six years of research, the results on weed control and yield using MB alternatives in strawberry nurseries still seem to be inconsistent. However, alternatives for strawberry fruit production were more promising. Several chemical fumigant alternatives applied under VIF film could be an appropriate short and medium-term solution when lethal soil-borne strawberry pathogens are at low levels, such as those found in Huelva. However, several aspects remain unsolved: Some of these chemicals are not registered yet in Europe and/or Spain, their environmental impact must be studied carefully and, EU policy on future agrochemicals use (included 1,3-D and/or chloropicrin) is uncertain due to the Directive 91/414/CEE (review of plant protection products placed on the market). For these reasons and others, important strawberry producing countries (United States, Spain, Italy, France, United Kingdom, Israel, and Australia) have applied for CUEs for the use of MB in 2005.

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TABLE 1: Treatments and yield (commercial runner plants harvested per $m^2$, 1998-2003).

| | 1998 | | 1999 | | 2000 | | 2001 | | 2002 | | 2003 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Locations:► | C.Ala. | Nav.1 | Are. | Nav.2 | Vin.1 | Nav.3 | Vin.2 | Nav.4 | Vin.3 | Nav.5 | Vin.4 | Nav.6 |
| Treatment: ▼ | | | | | | | | | | | | |
| MB(50/50)pe[1] | 53a | 48a | 52a | 51a | 67ab | 67ab | 63a | 78a | 56ab | 57a | 70a | 58a |
| MB(50/50)vif[2] | 55a | 44ab | 54a | 53a | 63ab | 83a | 50b | 69b | 64ab | 43ab | - | - |
| MB(33/67)vif | - | - | - | - | - | - | - | - | 57ab | 42ab | 65ab | 46a |
| Telopic pe | 39b | 38ab | 51a | 69a | 53bc | 53b | 50b | 72a | 62ab | 37b | - | - |
| TeloneC17pe | 46ab | 41ab | - | - | - | - | - | - | - | - | - | - |
| Telopic vif | - | - | - | - | - | - | 65a | 70a | 55abc | 42ab | 62abc | 44a |
| Pic pe | 38b | 35b | 53a | 59a | 62abc | 66ab | - | - | - | - | - | - |
| Pic vif | - | - | - | - | - | - | - | - | - | - | 58bcd | 41a |
| Dazomet | - | - | 48a | 56a | 55bc | 58b | 60b | 66a | 42cd | 37cd | 58bcd | 49a |
| MS pe | - | - | - | - | 53bc | 63b | 58a | 29b | 55abc | 49ab | - | - |
| MetamK pe | - | - | - | - | 68a | 62b | 48b | 34b | 53abc | 37b | - | - |
| DMDS pe | - | - | - | - | - | - | - | - | 47bcd | 40b | - | - |
| DMDS vif | - | - | - | - | - | - | - | - | - | - | 53cd | 44a |
| DMDS+pic vif | - | - | - | - | - | - | | | | | 58bcd | 51a |
| MS+pic vif | - | - | - | - | - | - | | | | | 68a | 44a |
| Propozonepe | - | - | - | - | - | - | | | | | 64ab | 43a |
| Untreated | 13c | 18c | 42a | 45a | 49c | 17c | 45b | 12b | 38d | 19c | 51d | 36a |
| P ≤ 0.05 LSD Test; [1]pe = applied under polyethylene film (LDPE); [2]vif = applied under VIF film | | | | | | | | | | | | |

TABLE 2: Demonstrations. Yield (commercial runner plants harvested per ha) in 2003.

| | | Locations | |
|---|---|---|---|
| **Treatment** | **Surface ($m^2$)** | **Cabezas Alambre (Avila)** | **Navalmanzano-Mudrián (Segovia)** |
| MB:pic (50:50) 400 kg/ha PE | 3,300 | 446,889 | 492,528 |
| MB:pic (50:50) 300 kg/ha VIF | 3,300 | 436,581 | 481,350 |
| Telopic 600 kg/ha PE | 3,300 | 382,221 | 426,984 |
| Telopic 300 kg/ha VIF | 3,300 | 372,618 | 346,962 |

TABLE 3: Treatments applied to soils prior to planting in 2002/03 and 2003/04.

| **Experiments 2002/03: 2 locations** | | **Experiments 2003/04: 2 locations** | |
|---|---|---|---|
| **Treatments[1]** | **Description** | **Treatments[1]** | **Description** |
| **Untreated** | | **Untreated** | |
| MB+pic (50-50) LDPE | [2]LDPE film, 200 kg/ha | MB+pic (50-50) LDPE | [2]LDPE film, 200 kg/ha |
| MB+pic (33-67) VIF | [2]VIF film, 100 kg/ha | MB+pic (33-67) VIF | [2]VIF film, 150 kg/ha |
| Dazomet-rot-VIF | [3]VIF film, 125 kg/ha | Dazomet-rot-VIF | [3]VIF film, 200 kg/ha |
| Dazomet-dir-VIF | [4]VIF film, 125 kg/ha | MS + pic VIF | [2]LDPE film, 200 kg/ha (MS) + 125 kg/ha (pic) |
| Telopic VIF (1,3D+pic) | [2]VIF film, 135 kg/ha | Telopic VIF (1,3D+pic) | [2]VIF film, 150 kg/ha |
| Chloropicrin VIF (pic) | [2]VIF film, 100 kg/ha | Chloropicrin VIF (pic) | [2]VIF film, 150 kg/ha |
| DMDS VIF | [2]VIF film, 200 kg/ha | DMDS + pic VIF | [2]VIF film, 125 kg/ha (DMDS) + 125 kg/ha (pic) |
| DMDS LDPE | [2]LDPE film, 400 kg/ha | Calcic cyanamid | [3]LDPE film, 700 kg/ha |
| Propozone LDPE (Propylene oxide) | [2]LDPE film, 250 kg/ha | Propozone VIF (Propylene oxide) | [2]VIF film, 250 kg/ha |
| [1]Treatments in the same row were applied to the same replications each year. [2] Shank-application under pre-formed beds mulched with black film. [3]Broadcast soil surface localization, rotovator and mulching with black film. [4]Localization under pre-formed beds mulched with black film | | | |

TABLE 4: Control of nematode populations at the end of the growing season.

| **2002/2003** | | | **2003/2004** | | |
|---|---|---|---|---|---|
| | **Loc. 1 Occifresa** | **Loc. 2 C. Malvinas** | | **Loc. 1 Occifresa** | **Loc. 2 C. Malvinas** |
| **Treatments** | ***Pratylenchus penetrans*[1]** | ***Meloidogyne hapla*[2]** | **Treatments** | ***Pratylenchus penetrans*[1]** | ***Meloidogyne hapla*[2]** |
| Untreated | 161.5 ab | 0.07 a | Untreated | 50.1 ab | 1.97 ab |
| MB+pic (50-50) LDPE | 23.2 bc | 0.00 a | MB+pic (50-50) LDPE | 6.3 b | 0.17 cd |
| MB+pic (33-67) VIF | 21.8 bc | 0.27 a | MB+pic (33-67)VIF | 0.3 c | 0.10 cd |
| Dazomet-rot-VIF | 65.3 bc | 0.00 a | Dazomet-rot-VIF | 112.0 ab | 1.40 bc |
| Dazomet-dir-VIF | 124.3 ab | 1.00 a | MS+pic VIF | 6.2 bc | 1.07 bcd |
| Telopic VIF | 5.5 c | 0.00 a | Telopic VIF | 9.8 bc | 0.00 d |
| Chloropicrin VIF | 110.0 bc | 0.00 a | Chloropicrin VIF | 83.8 ab | 0.00 d |
| DMDS VIF | 2.8 c | 0.00 a | DMDS+pic VIF | 12.7 bc | 0.00 d |
| DMDS LDPE | 93.5 bc | 0.00 a | Calcic Cyanamid | 51.5 ab | 2.80 a |
| Propozone LDPE | 320.9 a | 0.27 a | Propozone VIF | 242.0 a | 0.70 bcd |
| *P. penetrans*[1]: individuals/g roots; *M. hapla*[2]: Severity Index Scale: 0 (No symptoms) to 4 (all roots attacked); P ≤ 0.05. | | | | | |

TABLE 5: Experiments (2002/03 and 2003/04). Total commercial yield.

| **2002/2003** | **Total yield[1]** | **Relative yield[2]** | **2003/04** | **Total yield[1]** | **Relative yield[2]** |
|---|---|---|---|---|---|
| Untreated | 890 c | 84.5 c | Untreated | 800 c | 69.3 c |
| MB+pic (50-50) LDPE | 1053 a | 100 a | MB+pic (50-50) LDPE | 1155 ab | 100 ab |
| MB+pic (33-67) VIF | 1036 a | 98.4 a | MB+pic (33-67) VIF | 1165 ab | 100.8 ab |
| Dazomet-rot-VIF | 1014 ab | 96.3 ab | Dazomet-rot-VIF | 1067 b | 92.4 b |
| Dazomet-dir-VIF | 1025 a | 97.3 a | MS+pic VIF | 1101 ab | 95.3 ab |
| Telopic VIF | 1059 a | 100.6 a | Telopic VIF | 1122 ab | 97.2 ab |
| Chloropicrin VIF | 1038 a | 98.6 a | Chloropicrin VIF | 1193 a | 103.2 a |
| DMDS VIF | 1000 abc | 95.0 abc | DMDS+pic VIF | 1160 ab | 100.4 ab |
| DMDS LDPE | 899 bc | 85.4 bc | Calcic Cyanamid | 814 c | 70.5 c |
| Propozone LDPE | 985 abc | 93.6 abc | Propozone VIF | 1123 ab | 97.2 ab |
| [1]g/plant; [2]Relative yield in relation to MB standard treatment MB+pic (50-50) = 100%; P ≤ 0.01 | | | | | |

# SUBSTRATES AS AN ALTERNATIVE TO METHYL BROMIDE FOR STRAWBERRY FRUIT PRODUCTION IN NORTHERN EUROPE IN BOTH PROTECTED AND FIELD PRODUCTION

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## ABSTRACT

In the mid-1980s, substrate culture of strawberries developed mainly in The Netherlands and Belgium where strawberries are grown now intensively year round on small farms. Due to the limited available surface area and increasing knowledge on methods for growing vegetables and cut-flowers in soilless conditions, substrate culture of strawberries has gained much interest and has become a common cultivation method. In the 1990s the technique has spread in central Europe, mainly UK and the north of France and Italy. More recently, substrate culture has developed significantly in the southern regions of Spain, France and Italy due to the phase out of methyl bromide. On the other hand, the interest in northern Europe (Germany and the Scandinavian countries) is rather limited. Currently, the production area of strawberry soilless culture in Western Europe can be estimated around 1270 ha or 2.7 % of the total production area which is estimated to be around 47,000 ha.

**Keywords**: soilless culture, *Fragaria x ananassa*, strawberry production, greenhouse, substrates

## INTRODUCTION

Substrate systems have been of great interest to growers with intensive strawberry cultivation in greenhouses and plastic tunnels. Initially the soilless system was an alternative for strawberry production on contaminated soils (*Phytophthora* spp., *Verticillium* spp., nematodes) under permanent structures. The use of pesticides can be minimized and fruit rot and damage by grubs or other insects are limited. Strawberries from substrate culture are clean and well ripened because they are not touching the soil, straw or plastic but instead are hanging free in the air. By extending the production period, using cold stored plants, a continuity of supply to the markets is feasible which prolongs sales. Compared to imports and traditionally-grown strawberries premium prices can be obtained for separately-marketed, substrate-grown strawberries. The better working conditions of substrate-grown strawberries can attract labour more easily and increase picking speed. Out of season production enables the growers to divide the labour force over a longer period and to reduce peak harvest periods. Substrate systems also create the possibility of increasing plant density to increase both productivity and profitability to overcome higher installation and annual costs.

## OVERVIEW OF PRODUCTION AREAS IN EUROPE

### Northern Europe

In Scandinavia and Germany there is only limited interest in substrate culture. Land is available for crop rotation and soil disinfection is traditionally not being used and/or prohibited. In Scandinavia the fruiting season is limited by the climate. Strawberry production on substrate is more susceptible to frost and demands heating systems. Extending the production season in tunnels competes with high quality imports and can only be profitable for niche home markets.

Traditionally in Germany and Scandinavia grow most strawberries outdoors in the normal season. Pick your own systems still represent a relatively large percentage of the production. Germany has known only very recently tunnel culture and substrate production. Only about 20 ha is situated around high populated areas such as Berlin, Dusseldorf and Köln. In Scandinavia substrate culture does not exceed 10 ha.

### Central Europe

The greenhouse production is situated primarily in Belgium (160 ha) and The Netherlands (140 ha). In Belgium the acreage of substrate-grown strawberries in polythene tunnels fluctuates around 100 ha, which is 30% of the total surface under plastic. In The Netherlands it is around 30 ha. The use of soil disinfectants is restricted in The Netherlands (every 4 years based on soil analysis) and MB is not used in Belgium due to the high cost price and satisfactory results which are obtained with 1-3 dichloropropene (Telone). The reduction of herbicides and fungicides for traditional soil production makes growers switch from traditional summer production in the soil with waiting bed plants (sixty day plants) to substrate culture, especially in Belgium and The Netherlands.

The UK has expanded significantly the production of strawberries in greenhouses in the last 3 years to about 80 ha today. On the other hand, the strawberry production in the UK under portable and multispan tunnels has increased spectacularly from 150 ha in 1997 to around 1000 ha in 2004, of which about 75 ha is grown in peat and coir. Also, in the Republic of Ireland, tunnel production has boomed recently and now 16 ha of greenhouses and 25 ha of walk-in tunnels use substrates. Protected cropping still remains of marginal importance in Switzerland and Austria.

**Southern Europe**

MB is being used mainly in southern Europe to control nematodes and the fungal diseases *Phytophthora* spp and *Verticillium* spp. Research for alternatives to MB is global and substrate culture is one of the alternatives.

Although there has been a 30% decline in total strawberry acreage in France, over the past five years soilless culture has expanded significantly especially in the southern regions (from 70 ha in 1999 to 265 ha in 2004). The majority of substrate production occurs in multispan plastic tunnels. Initially, substrate culture started in the north of France; Pays de Loire (29 ha) and Nord Pas de Calais (10 ha). Now dominating regions are Lot-en-Garonne (87 ha) and Dordogne (65 ha). During the summer the day-neutral varieties are being cultivated on substrate culture in the region Dordogne. Production on substrate under glass is mainly situated in Bretagne (37 ha). Substrate culture has expanded also in the South-East Pyrenées and Rhône (33 ha).

In Italy, the soilless culture had aready developed in the last decade and has stabilized at a surface area of 150 ha. In the northern mountain area (Trentino and Alto Adige) strawberry soilless culture covers about 90 ha. In the Verona area, soilless culture covers about 40 ha which means 10% of the strawberry total surface. In the other Italian regions substrate culture is of minor importance: Cesena (2 ha), Battipaglia (12 ha), Metaponto (2 ha) and Sicily (4 ha).

The largest strawberry production area of Europe is situated in the south of Spain (Huelva). Almost 3000 ha are grown in large tunnels. Because of the ban of MB researchers are looking for alternatives and substrate culture has attracted interest. In the last two years substrate culture (peat, coir) has been established under large walk-in tunnels and multispantunnels. The area is estimated around 61 ha. Smaller substrate production sites can be found in Almeria and Tenerife-island.

Portugal has expanded its soilless culture (45 ha) very recently in the Algarve and Alentejo regions (Lieten *et al.* 2004). The production areas in Europe are summarised in Table 1.

Table 1: Overview of the estimated strawberry production in Europe (2004).

| Country | Total surface in ha | Protected cropping in ha * | Substrate culture in ha ** | Tendency substrate culture in the near future |
|---|---|---|---|---|
| Belgium | 2250 | 470 | 330 | Stable |
| The Netherlands | 2200 | 170 | 200 | Small increase |
| United Kingdom | 3200 | 680 | 155 | Stable |
| Ireland | 200 | 66 | 35 | Stable/small increase |
| Germany | 11.000 | 80 | 20 | Small increase |
| Switzerland | 410 | 50 | 15 | Small increase |
| France | 3700 | 1480 | 265 | Strong increase |
| Italy | 3900 | 3025 | 150 | Small increase |
| Spain | 7000 | 1900 | 61 | Strong increase |
| Portugal | 600 | 300 | 45 | Increase |
| Greece | 365 | 320 | 1 | Stable |
| Austria | 1200 | 10 | 2 | Stable |
| Norway | 1790 | 10 | 0.5 | Stable |
| Sweden | 1900 | 15 | 3 | Stable |
| Denmark | 1060 | 5 | 1 | Stable |
| Finland | 4500 | 8 | 4 | Stable/small increase |

*Greenhouses and large tunnels ** Exluding Frag. vesca and including outdoor soilless production systems

## SUBSTRATES

The basic product for soilless culture being used is mainly peat moss. On the other hand, to contend with the regulations of the peatland exploitation, alternative sustainable substrates are being developed. Several organic materials such as wood fibres, composted pinebark, cork and vine shoots, coir dust and coir fibres are considered renewable resources without ecological drawbacks.

Polystyrene as additive and rockwool are not biodegradable and in some countries cannot according to environmental regulations be plowed into the land. Although rockwool can be recyled by the manufacturing companies the interest as substrate is very limited. Pure coir dust and coir fibres represent about a quarter of the market. Sometimes it is used as pure substrate, very often it is mixed with peat. Advantage of coir is that it can be compressed in bricks and rehydratated very easy which is cost-saving for transportation. However, coir can contain high concentrations of K, Na and Cl and fixates Ca, Mg and Fe. These can result in leaf and tip burn, inferior fruit quality, Fe-deficiency and Na-toxicity symptoms. For these reasons, coir has to be washed with a Ca / Mg / Fe-containing solution prior to planting.

In some regions of Europe, local waste products are being used as substrate such as pine bark in the south of France. In Italy there is natural production of perlite, which explains the popularity of this substrate in certain regions. Compost based on garden and crop waste is being used on a small scale as an alternative to peat in Belgium and The Netherlands. Sometimes compost can have a lack of air porosity and an high salinity content. Trials with grape bagasse are going on in Spain and Italy.

Several organic substrates can contain high carbon sources available for microbial activity which can lead to N-retention. Organic substrates should be composted long enough and in some cases prefertilised. Woodfibre has a high porosity, a low buffering capacity and an easily usable water content. Typical for woodfibre is its fast volume reduction and its high organic matter. Composted vine shoots are characterised by their high cationic exchange capacity. Like vine shoots, pine bark shows a high porosity value (a high air capacity) and a relatively low water-holding capacity so it needs more frequent irrigation (Longuesserre 2001).

In case substrates are re-used for a second crop cycle, leaching with water is necessary in order to remove excessive salts. Also freezing of peat substrates during winter improves their physical properties. However, re-used peat, especially for summer plantings, usually reduces vigour and yield by 8 - 10% (Lieten 2004). The re-use of coir mixtures can be sometimes more successful due to their more stable composition (Evenhuis *et al.* 2001). As a consequence of their specific physical and chemical properties irrigation schedules and nutrient solutions will need to be adjusted for alternative and re-used substrates.

## ACTUAL SOILLESS SYSTEMS

### Bag culture

The first experiments on pea bags were done in the mid-1970s with forcing cultures but became in the 1990s the main growing method in central Europe. The bags are small plastic co-extruded bags which contain between 8 and 18 liters of peat mixture, coir, pinebark or perlite. Due to the high costs of growbags, the labour (150 hrs/ha) for removing bags and extra costs for plastic waste at the end of cultivation, bags only represent about 15% of the area in The Netherlands and Belgium. In some European countries where the environmental laws on plastic waste are less strict more bags are used. Sales companies have some interest in compacted coir bags in relation to cheaper long distance transportation to France, Spain, Italy and UK but in general bag culture in central Europe is decreasing. Due to local production, perlite is mainly commercialized in plastic bags in Italy.

### Container, buckets, small pots

Dutch and Belgian growers started to grow strawberries in plastic buckets in the early 1980s. These PE-pots are about 22 cm high, 20 cm wide and can contain 5-7 liters of substrate. Bucket culture has developed since the mid-eighties and still represents about 20% of the production systems in Belgium and The Netherlands. Since the late 1980s several types of right-angled containers have been introduced. These containers are about 15 cm high, 20 cm wide and 50 to 60 cm long. They can contain between 10 and 20 liters of substrate. Containers now represent 60% of production in Belgium and The Netherlands and the system is being used in most European countries.

A variation on the buckets, small pots of 1.5-2 litres, has been developed in the 1980s. Advantage of the system are the cost savings in reduced substrate and the possibility of growing young plants directly in the pots and storing the pots completely with plants in cold storage which reduces labour. The system represents about 5% of the substrate surface in Belgium and the Netherlands, France, UK and Switzerland.

### Systems

Pots, buckets and containers can be filled with substrate with specially adapted machines with which also trays for plant production can be filled. After the harvest there is no plastic waste material. Substrate can be extracted by machine and composted. The support structures are suspended from the glasshouse roof or placed directly in the soil. The rows are usually about 1.2-1.3 m apart and approximately 1.2-1.5 m from the ground. In northern Europe, there is a wide variation of horizontal support systems being used. Buckets can be suspended from the greenhouses and tunnels. On larger farms, buckets and containers are usually placed in gutters (5 Euro/m²) which collect the drainage water (The Netherlands, Belgium). Smaller pots can be lodged into pre-drilled holes in PVC-pipes which serve as canals for the drainage water. In France and Italy they are placed on a support structure consisting of wooden piles and iron wires. A typical support structure for bags and containers consists of a cheaper iron framework on piles in which a plastic is folded so it can serve as gutter to collect the percolate (€2.5/m²).

## ECONOMICS

Soilless culture requires higher costs such as support structures (€2.5-5/m²), irrigation and fertilizer units (€2-3/m²) and substrate (€2.5/m²). The higher yields due to increased plant density, higher picking speed and premium prices which can be fetched for the separately-marketed strawberries can overcome the higher installation and annual costs and increase profitability.

The profitability depends also very much on the annual yields which can be obtained. In The Netherlands and Belgium with the cv. Elsanta two crops in a tunnel can be obtained - 6 kg/m² in spring and 3.5 kg/m² in autumn (€2.2 Euro/kg costs and revenues 8 €/m²). In the greenhouses three successive crops with Elsanta are normal: 6 kg /m² in spring, 3 kg/m² in the summer and 4 kg/m² in the autumn. The revenues are better then the traditional culture in the soil (costs €2.6 /kg and revenues €12 /m²). The costs are summarised in Table 2.

Table 2: Yield and costs in soil and soilless culture of cv. Elsanta in Belgium.

| | Tunnel production * | | Summer production ** | |
|---|---|---|---|---|
| | Soil | Soilless | Soil | Soilless |
| Yield (kg/m²) | 4.7 | 9.5 | 2.2 | 4.2 |
| Costs (Euro/m²) | 9.5 | 14 | 4 | 7.6 |
| Total income ( Euro/m²) | 13 | 29 | 6 | 11.7 |
| Profit (Euro/m²) | 3.6 | 15 | 2 | 4.1 |

* Spring and autumn ** 60 day plants

In France, yields are lower with varieties such as Gariguette (3.8 kg/m²) and Darselect (1.2 kg/m² in autumn and 4.5 kg/m² in spring) but due to superior quality the growers are paid very well on the markets (respectively costs €3.6 /kg and €2.10 /kg and revenues €13 /m² and €12 /m²).

## RECIRCULATION

Due to the environmental restrictions there will be strong control in Europe on the quality of the leaching of drainage water, particularly for $NO_3$, $PO_4$ and $SO_4$. In the future, closed systems may be regarded as a good ecological agrarian practice (GAP), avoiding pollution of the environment and saving on water sources. By recycling up to 25% of the water, 35% of the fertilizers can be saved (Lieten 2000; Longuesserre 2002) which can have economic advantages.

In Belgium and The Netherlands environmental laws require open soilless systems to be converted to closed growing systems and many new installations have been designed to accommodate water collection and water storage. The percolate from strawberry cultures has to be recycled or alternatively used for other crops.

Recycling implies more risks of rapid transmission of fungal diseases *(Fusarium, Phytophthora frag., Verticillium)*, bacteria *(Xanthomonas*), and nematodes which can easily lead to crop losses. Most fungicides are not registered in Europe for irrigation water application so the discharge water has to be disinfected prior to re-use. Several systems are used such as UV-radiation (Runia 1994) , slow sand and rockwool filtration (De Bruijn 1995; Wohonka 1992) which are preferred due to their flexibility of design and size, simplicity, reliability and relatively low installation costs. Prior to discharging the percolate into the environment the water has to be cleaned up by biofiltration. In several countries, vertical flow reed beds and surface flow systems (Bryan & Findlater 1991;Green & Upton 1991) are used to remove pollutants and nutrients from excess waste water from substrate cultures.

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# SUBSTRATE SYSTEM FOR PRODUCTION OF STRAWBERRY FRUIT IN SPAIN AND MEDITERRANEAN CLIMATES

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## ABSTRACT

Strawberry growers in Spain and other Mediterranean countries have for many years depended on methyl bromide / chloropicrin (MB/PIC) to control insect and soil-borne pests before planting. The future loss of MB after 2005 has initiated a search for alternative fumigants or new and modified productions systems such as soilless growing systems. Soilless growing systems can achieve a sustainable, efficient and environmentally-friendly growing system for strawberry production without the use of MB. Organic substrates like peat, coconut fibre, grape bagasse compost, composted cork or inert substrates like rockwool or perlite are feasible. Soilless systems can be adapted to fix a wide variety of economic situations from low capital input to high capital input. Substrates usually give higher yields than when MB is used in the open field, they extend the growing season and allow harvesting at a time when the prices are best. The removal of MB as a viable fumigant has acted as a catalyst for the widespread and ongoing development of new and modified technologies like the soilless growing systems.

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

## INTRODUCTION

Strawberry production consumes the largest amounts of methyl bromide (MB) in Spain. With the phasing out of MB as a soil fumigant by 1 January 2005 in all developed countries, the strawberry industry is facing an urgent priority to find an alternative fumigation system. De Barro and Edwards (1995) concluded that the removal of MB acted as a catalyst for the widespread and ongoing development of new and modified technologies like the closed soilless growing systems.

Systems for recycling the nutrient solution are available and provide a more sustainable use of water and nutrients. Closed soilless growing systems may lead to environmentally-friendly systems and thus to a sustainable horticultural sector. The sustainable system may replace the soil grown system where MB is used in Southern Europe and the run-to-waste soilless system in Northern Europe.

De Barro and Edwards (1995) showed that strawberry production without MB is possible using soilless crop with peat as substrate, and emphasized the following advantages:

a) Soil disinfection is not necessary thereby avoiding MB and other disinfectants;
b) Soilless system is hanging so the plants and the fruit are not in contact with the soil
c) Conditions around the plant are much drier, so *Botrytis* is no longer a problem
d) Integrated pest management is much more effective
e) Fruit picking is very comfortable as the fruit remains at an accessible height
f) Residues are minimal as the substrate can be reused or used as an organic additive to the soil; and plastic bags can be recycled.

In a closed soilless growing system, contamination of soil and surface water is reduced, although 100% efficiency in water and fertilisers use has not been achieved yet (Van Os, 1999a).

Pathogen microorganisms that are transmitted in the re-circulating soilless crops are *Phytium, Phytophthora, Verticillium, Fusarium, Xanthomonas, Erwinia,* etc., virus and nematodes. Lixiviates must be filtered, disinfected and re-introduced to the closed circuit, correcting the ionic composition (when possible), and in an automatic process.

The main method of disinfection of lixiviates are: Heat treatment, Ozone and Hydrogen peroxide treatment, ultraviolet radiation, membrane filtration, chlorination or iodination and slow sand filtration. Slow sand filtration is the only biological disinfection method in which the nutrient solution is not sterilized and thus the development of certain microflora takes place and can fulfil an important role in disease suppression (Van Os 1999b).

## SUBSTRATES

Strawberry crop in soilless systems began in Huelva (Spain) in 1997. Since that time there has been a rapid increase in the number of hectares of soilless production each year (Figure 1). In addition, there is approximately 50 ha in the Canary Islands and a some near the Mediterranean coast (Almería, Murcia, Valencia, Barcelona, etc.).

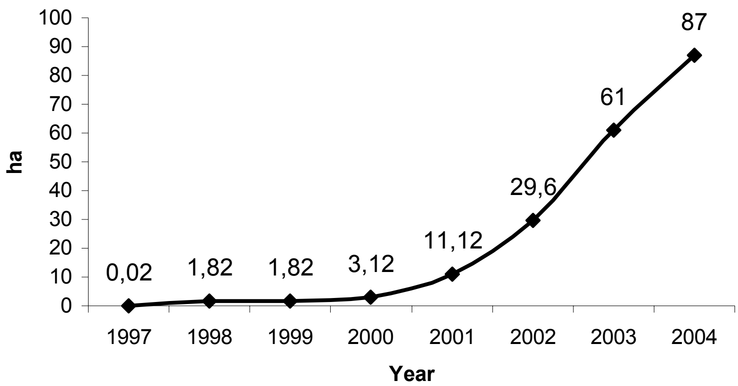


Figure 1.- Total area in Huelva (Spain)

### Types of soilless systems

Production is carried out under high tunnels and plastic greenhouses with or without heating. There are several alternatives of open soilless systems. The common system is the one based on hanging trays or placed on a support structure made with wooden post and wires or corrugated iron. Height above the soil: 1,5 m.; distance between lines: 0,5 -1 m. and planting density: 11 - 22 pl/$m^2$. The type of plants is typically bare root fresh plant. The period of production is from November to June. Under these conditions the yield obtained is about 600 to 700 g/pl at low densities, which means 6.5 to 7.5 kg/$m^2$.

Another option is the pyramid layout: Distance between pyramids: 2-3 m; Number of levels: 5 . Planting density: 10 pl/ml, equivalent to 33-45 pl/$m^2$. With this system, the yield is about 200 to 300 g/pl, which means 8 and 10 kg/$m^2$ respectively. Today only 2 levels pyramids are recommended. In Almería (Spain) experiments are being carried out with incline or vertical espalier.

### Substrate types for strawberries

Substrates that are usually used for strawberries are: Peat, coconut fibre, rock wool, perlite and alternative substrates such as grape bagasse or composted cork. Some materials can be mixed together.

Peat is commonly used as substrate in strawberry soilless growing system, but is a non renewable source. These have to be washed out of the substrate before planting. Peat provides a better water buffer than coconut fibre or rock wool. Reuse of peat is not recommended, however, reuse of coconut fibre is possible (Evenhuis *et al.* 2001). Coconut fibre can contain rather large amounts of Na, Cl and K.

**Yields**

Practically any substrate can be used to grow strawberries with a soilless system, provided that it is adequately managed. There are substrates that require more experience, therefore substrates easier to use and with good yield results are recommended, like coconut fibre, and with a volume of 10-25 l/m.

Table 1 show that coconut fibre is one the best substrates with earlier and with greater total yield than conventional crops. There are no differences between open and closed systems although the open system resulted in greater yield. Soilless culture with tray plants allows earlier planting, increasing considerably the early yield. This consequence could improve the profitability of these systems and diversify the concentration of the production of strawberries during the growing season (Peralbo *et al* 2004).

Table 1: Total yield in open and closed system with different substrates (kg/ha)

| | **Open system** | **Closed system with slow sand filtration** |
|---|---|---|
| Cork composted | 52328 | 38368 |
| Peat | 57270 | 52752 |
| Coconut fiber | 78268 | 72839 |
| Perlite | 55021 | -------- |
| Field | 60771 | |

## ECONOMICS

Substrate soilless systems can be adapted to fix a wide variety of economic situations from low capital input to high capital input. They usually give higher yields than mb, extend the growing season and allow harvesting at a time when the prices are better (Figure 2).

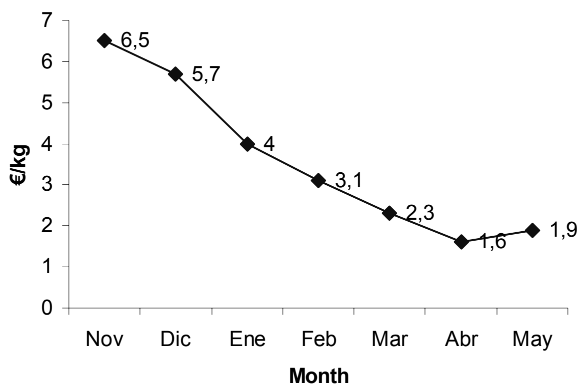


Figure 2.- Wholesale prices of hydroponic strawberries (€/kg).

The cheapest system under unheated high tunnel has an initial installation cost of € 5-7 /m$^2$, with an annual variables cost of € 3 - 5 /m$^2$ and a gross revenue around € 20–21 /m$^2$ with good prices due to the off-season production (until January) and the early yield (until April), which are from 65 to 75% of total yield. Thjs allows a net revenue around € 9-10 /m$^2$. Hydroponic strawberries usually get better prices than the traditional production system, around € 0.60 to 1 /kg better price. Traditional system in soil costs € 2.8–3 /m$^2$ with a gross revenue around € 4–5 /m$^2$, which means a net revenue € 1-2 /m$^2$. In general, the profitability is variable every year because it depends on the market.

**STRAWBERRY QUALITY IN SOILLESS SYSTEMS**

Consumers measure the quality of the fruit in terms of visual appearance (form, colour, size), texture, flavour and aroma. However, the nutritional quality and food safety are also of great importance (Skupien *et al.* 2004). Strawberries are 95% water and 5% dry matter. Proteins, lipids, sugars, vitamins and mineral content is variable and changes according to the variety, the handling carried out in the production, the climate and the production region as well as sampling time and degree of ripeness. Therefore many variables can affect the nutritive value of strawberries (Kallio *et al.* 2000; Hakala *et al.* 2003).

In general, the soilless system has a lower soluble sugar content and a higher malic acid content, although the total acidity is practically the same for both systems (Table 2). The total soluble sugars/titratable acidity ratio is higher in strawberries cultivated in soil. The anions and nitrogen contents are higher in soil culture except chloride that is higher in the soilless systems (Fernández et al 2004).

Table 2. Mean values for variables according culture system

| **Quality attribute** | ***Soil*** | ***Soilless*** | **Quality attribute** | ***Soil*** | ***Soilless*** |
|---|---|---|---|---|---|
| *Moisture* | 88,99 | 89,11 | *Al* | 0,50 | 0,49 |
| *pH* | 3,68 | 3,58 | *Cr* | 0,07 | 0,07 |
| *Acidity* | 0,57 | 0,60 | *Cu* | 0,65 | 0,57 |
| *N* | 1,17 | 1,05 | *Fe* | 4,97 | 4,92 |
| *Sucrose* | 2,31 | 1,73 | *Zn* | 3,95 | 3,29 |
| *Fructose* | 21,36 | 18,91 | *Ba* | 0,27 | 0,11 |
| *Glucose* | 15,69 | 13,38 | *Ca* | 180,73 | 139,28 |
| *Citric acid* | 6,07 | 6,03 | *K* | 830,68 | 924,34 |
| *Succinic acid* | 1,02 | 0,94 | *Mg* | 106,95 | 99,38 |
| *Malic acid* | 1,27 | 1,45 | *Mn* | 3,32 | 3,71 |
| *Chloride* | 86,95 | 92,74 | *Na* | 8,86 | 13,24 |
| *Nitrite* | 63,94 | 55,17 | *P* | 18,99 | 17,84 |
| *Nitrate* | 71,72 | 59,25 | *S* | 48,90 | 41,35 |
| *TSS* | 39,36 | 34,02 | *Sr* | 0,56 | 0,86 |
| *TSS/TA* | 5,04 | 4,06 | | | |

Strawberries cultivated traditionally in soil have slightly higher concentrations of key elements. Only K, Mn, Na and Sr have higher values in the strawberries cultivated without soil. Discriminant analysis was applied to experimental data and the best percentages of correct classification were obtained for strawberries cultivated without soil (100%). For the strawberries cultivated in soil the percentage of correct classification is inferior (83%). Only one sample of strawberries of this group was misclassified. Figure 3 shows the graphical representation of the projections of the points of each group on the plane defined by the canonical axis (function 1). The sets of points show a distribution pattern in which two well-defined groups can be distinguished. The difference between two groups (with or without soil) arises mainly from the Ba, Cr, pH and sucrose.

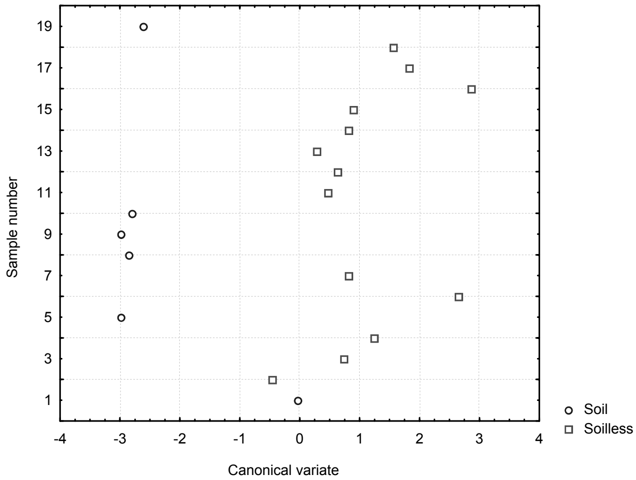


Figure 3. Scatterplot of canonical variate.

In conclusion, the results of MANOVA shows that effect of the cultivation system (with or without soil) on the nutritional characteristics of the strawberry was not significant, although, in general, the strawberries cultivated without soil have a lower content of all the parameters studied except malic acid, chloride, potassium, manganese, sodium and strontium.

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**USE OF 1,3-DICHLOROPROPENE / CHLOROPICRIN FOR THE PRODUCTION OF STRAWBERRIES IN SPAIN**

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## ABSTRACT

Agroquímicos de Levante (AQL) has registered in Spain four formulations of 1,3-dichoropropene / chloropicrin mixture (sold as Agrocelhone™) for use on strawberries, peppers, tomatoes, onions, tobacco and carnations. It is efficacious against nematodes, fungi and germinating weed seeds. The product is 40-60% less expensive than MB depending on the crop, method of application and production system. It is therefore a cost-effective substitute for the ozone-depleting fumigant MB. Agrocelhone is registered in Lebanon, Chile, Cuba and Morocco. Registration is pending in Greece, Guatemala, Costa Rica, Jordan, Argentina, China and Australia.

**Keywords:** Agrocelhone™, methyl bromide, 1,3-dichloropropene, chloropicrin, nematodes, soil fungus, peppers, strawberries, cut flowers

## INTRODUCTION

Agroquímicos de Levante (AQL) has specialised in soil disinfection treatments since 1984 and now sells fumigants to 80% of the Spanish market that used methyl bromide (MB). AQL has also developed expertise in the delivery of fumigants through mechanized injection and AQL-patented machinery. AQL approved a research programme aimed at finding alternatives to MB in 1996 when it was clear in 1995 that the phase-out of MB would take place in 2005. The first results of this programme came in 2000 when Agrocelhone™, a mixture of 1,3-dichloropropene (1,3-D) and chloropicrin (PIC) was first registered in Spain. Since this time various formulations have been registered and these are shown in Table 1.

Table 1: Composition of the products in (weight/weight)

| | 1,3-dichloropropene | Chloropicrin | Formulation |
|---|---|---|---|
| Agrocelhone™ N | 61.1% (w/w) | 34.7% (w/w) | AL |
| Agrocelhone™ NE | 60.8% (w/w) | 33.3% (w/w) | EC |
| Agrocelhone™ F | 40.6% (w/w) | 56.7% (w/w) | AL |
| Agrocelhone™ FE | 36.7% (w/w) | 52.8% (w/w) | EC |

## PROPERTIES OF THESE PRODUCTS

Agrocelhone™ is a liquid fumigant active against nematodes, soil fungi, and germinating weed seeds. It is applied in the soil before sowing or planting. It is classified as Very Toxic (T+) but it is less dangerous for technicians that apply the product as it is a liquid and not a gas under pressure. Agrocelhone™ is degraded in the soil which avoids residues in the fruits. The product is not phytotoxic provided the safety period is observed. Agrocelhone™ is effective when applied to a depth of 10 cm and when the soil temperature is 10-40 ºC. Agrocelhone™ can be applied by mechanized injection or through drip irrigation.

### Mechanized injection

*Localized treatment in the bed:* The treatment is carried out with machines that prepare the bed where the crop will be implanted and, at the same time, the product is injected and sealed in the bed with Virtually Impermeable Film (VIF).

*All-terrain treatment in alternating bands:* The treatment is carried out with machines that inject the product into the soil to a depth of 25-60 cm depending on the type of crop to be planted and sealed with PE film. The treatment is carried out twice in alternating bands, the first time the treated surface is 2.5m wide and the second time the bands not treated are 2.35m wide. The second application is applied about 15 days after the first one. The film from the first application is removed and re-laid 2.50m wide, thereby treating 100% of the soil.

*Localized treatment in flat:* The treatment is carried out with injection machines using the same system as All-terrain above, but everything is done in one pass and the treatment is localized in the plantation line.

**Drip irrigation**

*All-terrain treatment:* The treatment is carried out through the drip irrigation and the dripper lines are put only in the plantation lines. The PE film is put in the plantation line.

*Localized Treatment:* The treatment is carried out through the drip irrigation and the dripper lines are set halfway at 50 cm. The soil is totally covered.

**CROPS IN SPAIN**

Agrocelhone™ is registered for use in Spain for the production of strawberries, peppers, tomatoes, onions, tobacco and carnations. Of these, strawberry and peppers and the most economically important and have consumed the most MB in the past. Details are therefore provided on these two crops.

Strawberry (Huelva Province)

Agrocelhone™ N, NE and F are registered for use on strawberries in Spain. Agrocelhone™ N (injectable) was authorized in 2000 for strawberry crop using the same technique and machinery for MB injection, but with some modification. Cost comparisons of Agrocelhone™ N with MB are shown in Table 2. Over time, Agrocelhone™ N has taken the share of the market away from MB (Table 3).

Table 2: Comparative costs of methyl bromide (MB) with Agrocelhone™

| | Cost/kg | Rate-Dosage | Film cost | Film consumption | Applic -ation | TOTAL |
|---|---|---|---|---|---|---|
| MB/PIC 50/50<br>Agrocelhone™ N | 4.60 €/kg<br>3.20 €/kg | 200 kg/Ha | 1,25 €/kg | 415 kg/Ha | 144 € | 1,583 €<br>1,303 € |

Table 3: Percentage share of the AQL market

| | 2000 | 2001 | 2002 | 2003 | 2004 (Forecast) |
|---|---|---|---|---|---|
| MB/PIC 50/50 | 65% | 45% | 40% | 42% | 47% |
| Agrocelhone™ N | Trials | 10% | 14% | 11% | 13% |
| Agrocelhone™ N and NE (ha) | ---- | 800 | 1,120 | 880 | 1040 |

In 2002, Agrocelhone™ NE was authorized to allow treatment of the root zone which allowed the product to be applied without any modification in the bed-forming machines, thereby saving application time. Agrocelhone™ F was registered in 2003 with increased concentrations of chloropicrin aimed at controlling mainly fungal disease.

**Peppers (Murcia Province)**

Alternatives registered are Agrocelhone™ NE (nematicide/fungicide) and FE (mainly fungicidal) formulations, both applied through drip irrigation. Peppers are grown in greenhouses in Murcia. The product is applied manually as it is not possible to use the machinery used for soil treatments inside the greenhouse. The cost comparisons between each formulation are shown in Table 4.

Table 4: Comparative costs of methyl bromide (MB) with the cost of Agrocelhone™ treatments.

| | Cost/kg | Rate-Dosage | Film cost | Works and application | irrigation | TOTAL |
|---|---|---|---|---|---|---|
| MB/PIC 98/2 | 5.60 €/kg | 400 kg/ha | 3.90 €/kg (VIF) | 888 € | ---- | 4,298 €/ha |
| Agrocelhone™ NE AT[1] | 3.90 €/kg | 500 kg/ha | 1.60 €/kg | 830 € | 181 € | 3,380 €/ha |
| Agrocelhone™ NE B[2] | | 300 kg/ha | | 849 € | 80 € | 2,339 €/ha |

[1]AT – All-terrain Treatment; [2]B – Localized Treatment

## AGROCELHONE™ USE IN OTHER COUNTRIES

**LEBANON** Agrocelhone™ is used commercially for the production of vegetable crops mainly. Agrocelhone™ is being trialled on strawberries and carnations.

**CHILE** Agrocelhone™ was registered in 2003 and is the first South American country for AQL. It is used mainly in grape, tomato and strawberry production.

**PORTUGAL** Agrocelhone™ is registered for use in Portugal for tomato, strawberry, cut flower and tobacco production. Trials on these crops showed AGROCELHONE™ could effectively replace MB.

**CUBA** Registered for tobacco and vegetables in general. Sales are expected to commence shortly.

**MOROCCO** Agrocelhone™ was registered in 2003 for use on tomatoes and strawberries. Trials on these crops showed Agrocelhone™ could effectively replace MB. The comparative costs of Agrocelhone™ in Morocco compared to MB are shown in Table 5. The share of the market in 2004 in Morocco for Agrocelhone™ is shown in Table 6.

Table 5: Comparative costs of Agrocelhone™ in Morocco, compared with methyl bromide (MB)

| | Cost/kg (applied) | Rate-Dosage | TOTAL |
|---|---|---|---|
| MB/PIC 98/2 | 56 Dirhams/kg – 5.09 €/kg | 240 kg/ha | 13,440 Dh/ha – 1,222 €/ha |
| Agrocelhone™ NE | 50 Dirhams/kg – 4.54 €/kg | 180 kg/ha | 9,000 Dh/ha – 817 €/ha |

Table 6: Percentage share of Agrocelhone™ in the market of Morocco

| | 2004 |
|---|---|
| MeBr 98/2 | 90% |
| Agrocelhone™ NE | 8% |

Agrocelhone™ is being registered in Spain for use on carrots, grapes, potatoes, eggplants, beans and cucumbers. Registration is pending in Greece (for use on strawberries, tobacco, eggplants, cucumbers, tomatoes, Guatemala) Costa Rica, Jordan (soil disinfectant for all crops), Argentina tobacco, strawberries, strawberry nurseries and tomatoes, China (for tobacco and strawberries) and Australia (strawberries).

## CONCLUSIONS

AQL has addressed the phase out of MB with the development and implementation of several products that can be applied in different formulations by machinery appropriate to the crop and growing conditions. Agrocelhone™ is efficacious against many soil borne pests, including nematodes, fungal diseases and germinating weed seeds, in a diverse range of crops and soil types. Agrocelhone™ is 20-40% cheaper than MB depending on the cropping system. It is therefore a cost-effective substitute for MB. AQL is willing to collaborate with any government that requests trials that will lead to the replacement of MB. The use of Agrocelhone™ can be adapted to any crop and growing system.

# THE USE OF FUMIGANTS AND GRAFTED PLANTS AS ALTERNATIVES TO METHYL BROMIDE FOR THE PRODUCTION OF TOMATOES AND VEGETABLES IN ITALY

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## ABSTRACT

Methyl bromide (MB) has been the product of choice in Italy which has been Europe's largest consumer. More recently, some of the uses of MB have been replaced by grafted plants, soilless cultivation, and separate applications of 1,3-dichloropropene (1,3-D) and chloropicrin (PIC). The plants are grafted onto resistant rootstock that are resistant and/or tolerant to fungal diseases and in some cases nematodes. Melons, watermelons, tomatoes and eggplant are produced from grafted plants. Grafting reduces the use of MB. The is now some experience in soilless cultivation. However, the expansion of soilless cultivation is constrained by the costs of modernising greenhouses and the lack of locally-available expertise. Viable chemical alternatives to MB include 1, 3-D and PIC. Both have been registered in Italy for separate applications since July 2002. Today, 45% of the area once fumigated by SIS with MB is now treated with 1, 3-D and PIC and covered with Virtually Impermeable Film (VIF). Specialised machinery is used to safely and effectively apply the fumigants and VIF. Compared to MB, weeds are not always effectively controlled and plant back time is delayed. Farmers are also entrenched in the use of MB and reluctant to use VIF. Despite these limitations, the alternatives to MB are becoming more widely used.

**Keywords**: 1,3-dichloropropene, chloropicrin, soilless cultivation, grafted plants, methyl bromide, alternatives, resistant rootstock, nematode, melon, watermelon, tomato, eggplant

## INTRODUCTION

SIS S.p.A. is the largest Italian company working in the field of soil fumigation. For several decades methyl bromide (MB) was the product of choice in agriculture for assuring the broadest coverage against fungi, nematodes and weeds. Italy has been Europe's largest consumer of MB.

SIS spa provides Italian farms with professional services in soil fumigation:

- Through a network of technical assistance provided by 40 qualified agronomists in every part of Italy;
- With actual licensed, specialised personnel working in teams on the ground;
- With specialized machines/equipment, manufactured within the company

Following a series of decisions taken at an international level in the mid-1990's restricting the future use of MB, SIS has focused on the research for viable alternatives by:

1. Experimentation and production of grafted plants;
2. Experimentation and production in soilless cultivation;
3. Experimentation and subsequent introduction of chemical solutions compatible with the objectives of greater environmental protection.

## GRAFTED PLANTS

Centro Seia, owned by SIS, is a nursery for seedling production. Modern, situated in the south of Sicily, Centro Seia covers more than 5 hectares of greenhouses and produces about 70 million plants per year, distributed all over Italy and certain European countries.

Every year millions of plants are grafted onto rootstock resistant and/or tolerant to fungal disease and, in some cases, to nematodes. These methods are proving to be very effective and the use of such plants is expanding, especially among the more qualified growers.

Nearly all our watermelons are grafted, as are a great number of the melons. For some years now there has been a steady rise in the demand for grafted tomatoes and, in the last two years, a veritable explosion in demand for eggplant.

Grafting significantly reduces the use of MB and guarantees to farmers optimal performance in terms of consistency in quality, conformity in size and resistance to cold in winter.

## SOILLESS CULTIVATION

SIS has dedicated a sector of its business to the production of a flavoursome tomato in soilless cultivation. Six hectares of land have been set aside as a model for this method of growing. The result is a high quality fruit which permits us to supply some of the most important European distribution chains during the autumn-winter-spring period.

This same model is now being emulated by some of the more innovative growers. However, this very same experiment on our part has exposed precisely the difficulties involved in transferring this method of production into the Mediterranean agricultural context. The causes of these are to be found in the costs involved in the modernisation of greenhouses and in the lack of technical expertise in soilless cultivation which is not yet readily available in Italy.

## VIABLE CHEMICAL ALTERNATIVES

For some years now SIS spa has been collaborating with some of the main international companies engaged in the research of substitutes for MB. In particular we have lent our support in conducting the efficacy trials necessary for the registration of new fumigants.

- November 2001: Registration of TELONE EC, nematocide fumigant, the only formulation in Italy based on 1,3-dichloropropene (1,3-D) which is authorised for use in greenhouses (Dow AgroSciences B.V.);

- July 2002: Registration of TRIPICRIN, based on chloropicrin, fumigant with fungicidal and herbicidal action (Triagriberia S.L.)

Since 2002 SIS spa has been committed to converting land that has been treated with MB to treatment with 1,3-D and PIC

| Year | % Converted areas | No. of growers involved | No. of applications |
|---|---|---|---|
| 2002 | 5% | 200 | 465 |
| 2003 | 36% | 1,534 | 2,931 |
| 2004 (August, estimate) | 45% | 2,000 | 4,000 |

Both 1,3-D and PIC are applied with the aid of machinery specially designed by SIS and in cooperation with company's specialised dosage system.

In open fields, SIS spa uses tractors that inject fumigants separately into the deep layers of the soil while simultaneously laying out sheets of virtually impermeable films (VIF), using a method which seals the edges of the films together, thereby blocking the escape of gaseous emissions into the atmosphere.

Inside the greenhouses on the other hand, the products are applied in water through the pipes of the irrigation systems. They are emulsified in water and dispensed, again separately, on ground previously covered with VIF.

Our specially designed machines deliver specific amounts of water together with the correct proportions of the products. Electronic devices continually check that the amount of water delivered, water pressure, concentration and dosages of fumigants fall within set parameters.

As we have noted in both of the systems above, the products are measured and delivered separately. The clear advantage of this, compared with systems of mixing products together, is that it allows for greater flexibility in addressing the particular needs of any given soil, in relation to the type and the degree of infestation.

The growing satisfaction of our customers, together with significant quantitative results achieved in the first two years of commercial use of 1,3-D and PIC, indicates that the traditional usage of MB can be viably substituted in the majority of cases. In addition, the cost of the new products competes favourably with that of MB.

Some limitations of 1,3-D and PIC have been noted and can be summarised as follows:

- Weed control in open fields is not always as effective as it is with MB;
- Plant back time, which is the interval between application of the products and planting, is much longer than MB and causes delays in some sectors;
- Considerable problems have surfaced with farmers who are fixed in their habits with regard to the use of MB. This means that the work of our agronomists and our specialised licensed workers is imperative, not only in educating farmers in ground preparation and so on, but also in checking the efficiency of irrigation systems,
- There remains some resistance by farmers to the use of VIF, notwithstanding the reasonably contained price of the product.

Without denying the limitations outlined above, the reality is that the substitution of MB is nevertheless in motion and with overall positive results.

It should be added that the fact that PIC can only be given by licensed, specialized personnel means that the product can be traced thereby increasing the guarantees with respect to storage, transport and application.

## COLLABORATION

Of particular value for SIS has been the collaboration it has forged with various universities and research centres. Work carried out with the Universities of Torino, Portici, Piacenza, Pisa, Davis (CA, USA), and with CNR of Bari, has allowed us to deepen our fundamental knowledge on the subject and to perfect soil fumigation techniques in our continued struggle against soil parasites.

Finally, SIS spa actively collaborates with industrial companies with the view to registering new products based on dimethyl disulphide (Atofina), Iodomethan (Arvesta), a combination of MB and PIC (DSBG), a combination of 1,3-D and PIC (Dow Agro Sciences).

# THE USE OF BIOFUMIGATION WITH NEW TYPES OF SOLARISATION FILM FOR STRAWBERRY PRODUCTION IN SPAIN

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## ABSTRACT

Strawberry production in Huelva (Spain) was compared when the soil was solarized with LDPE film or sprayable plastic polymers, both combined with biofumigation. Sprayable plastic polymers, unlike LDPE film, tend to be less susceptible to damage by the weather and animals. These polymers form a permeable membrane that heats up the soil to control soil-borne pathogens. When compared with the LDPE film, the polymers alone or combined with simultaneous sprinkler-irrigation with metam sodium showed similar control of soil-borne pathogens and strawberry yield. The costs of some treatments with the polymers were similar to the standard MB:PIC shank-applied treatment, while others were up to 25% more expensive. Further trials on a larger scale are planned as this treatment appears to be a promising alternative to the ozone depleting fumigant methyl bromide which must be phased out for soil disinfestation in developed countries by 2005.

**Keywords:** strawberry, plastic polymers, solarization, LDPE film

## INTRODUCTION

The strawberry industry in Spain is concentrated in the coastal area of Huelva (Southwestern Spain). Around 6,500 ha is planted in strawberry and a production of 270,000 tonnes has been estimated for 2003. Strawberry ground is fumigated with shank-applied methyl bromide (MB):chloropicrin (PIC) (50:50 w/w; 200 kg/ha) under mulched beds annually in September. Due to the international phase out of MB in developed countries under the Montreal Protocol, a specific project was initiated in 1997 to find technically and economically feasible alternatives. More recently, there is concern that chemical alternatives to MB may not be re-registered in the EC due to the Directive 91/414/CEE. To overcome the elimination of MB and to overcome concerns on re-registration, this project aimed to find not only chemical but also non-chemical (physical, mixed and biological) alternatives to MB.

Soil solarization is an example of a physical treatment used to heat the soil to control soil-borne pests. We have trialled solarization in combination with biofumigation (Sol+Biof) on the Experimental Farm 'El Cebollar' ('the Farm') since 1999. Strawberry production was initiated on the farm in 1991 and MB has been never been applied. Strawberries were grown without any kind of soil fumigation between 1991 and 1994. Soil solarization with LDPE transparent film was applied between 1995 and 1998 and Sol+Biof from 1999 until today.

The main advantages of Sol+Biof in comparison with soil solarization that we observed were: 1) An increase in organic matter content of soil; 2) Better control of weeds, particularly common purslane (*Portulaca oleracea)* which is very frequent in summer; 3) Better vegetative development and pattern of productivity. Importantly, Sol+Biof increased the yield of 'Camarosa' (57,500 kg/ha) compared to the average productivity of this cultivar on the Farm (Medina-Mínguez 2002).

Sol+Biof is not expensive compared to the standard cultivation practice currently used by strawberry farmers since it requires only the LDPE film and the cost of installing and removing it. The biofumigant manure is similar to that commonly used by growers: fresh (for biofumigation) and dry (fermented) as organic amendment applied annually. The cost of Sol+Biof is €850/ha which is about 24% less than the standard shank-application of MB:PIC in the area of Huelva (€1,120/ha). In addition, *Meloidogyne hapla* populations present on the Farm in the summer of 2003 were controlled with this treatment as the manure was incorporated deep into the soil using a rotovator instead of a disk-harrow.

Despite the benefits of LDPE film, there are practical problems associated with its use. It can be torn by the wind and hail and damaged by domestic and wild animals which then reduces the film's ability to heat the soil. Strawberry farmers in Huelva have stated that they do not trust physical and mixed MB alternatives, and in particular soil solarization. Field scale demonstrations carried out in 2001/02 with several mixed alternatives previously tested in other locations of Huelva (1997/98-2000/01) (Sol.+Biof and Sol+MS) showed inconsistency in yield and nematode control in comparison with standard MB:PIC and other chemical alternatives to MB. This resistance to using soil solarisation has both a practical and psychological basis to it and remains despite current and past efforts to transfer the technology (López-Aranda, 1980a, 1980b).

New sprayable plastic polymers ('polymers', Gamliel *et al.* 2001) could be a better than LDPE film as they form a membrane in contact with the soil, maintaining high soil temperature and humidity like LDPE film, but they are more flexible and are not so easily damaged by the weather. The polymers allow simultaneous sprinkler irrigation with chemical fumigants at reduced rates (less 30%) such as metam sodium (MS), formalin and others. Gamliel *et al.* (2001) have reported control of several soil-borne fungi like *Sclerotium rolfsii*, *Fusarium oxysporum* or *Verticillium* spp. using these polymers when combined with simultaneous irrigation with formalin. Importantly, in combination with organic amendments it was possible to control *Rhizoctonia* spp. and *Verticillium* spp.

We present the results of trials that compare soil solarization (LDPE film) with new sprayable plastic polymers as solarization-like alternatives, both combined with biofumigation.

## METHODS

The main steps of our Sol+Biof system using LDPE film are as follows:

1) Copious sprinkler irrigation until the field capacity content of soil is reached. First week of July.
2) Application and immediate soil incorporation (with disk-harrow or rotovator) of 25,000-30,000 kg/ha of fresh chicken manure. This kind of fresh manure is rich on husk of rice. Second week of July.
3) Short sprinkler irrigation to restore water losses due to soil evaporation, just before LDPE application. Third week of July.
4) Application of LDPE transparent film sheets (50 microns) in strips 3.30 m wide and 0.35-0.40 apart, with special prototype solarizator developed by the INIA project. Third week of July.
5) Sol+Biof effect on the soil for 5-6 weeks. From third week of July up to end of August.
6) Remove LDPE and rake with disk-harrow or cultivator to homogenize the solarized soil.

Experiments with the polymers were started on the Farm in the summer of 2003. Black sprayable plastic polymer Solartex® (Ecotex Soil Mulch Products Ltd, Israel) was used in our first trial. It is a biodegradable plastic polymer applied as spray to wetted soil at field capacity.

This first trials used 9 treatments in large plots (25 x 3.40 m per treatment) without replicates (Table 1). Treatment B (Sol+Biof) represents a standard fumigation on the Farm and treatment C is similar except that plastic LDPE sheets were replaced by Solartex® (800 l/ha).

Table 1: Fumigant treatments applied to soils prior planting.

| Treatments | Description |
|---|---|
| A. Untreated | Control without soil fumigation |
| B. LDPE.+ Biof. | Soil solarization in combination with 3 kg/m$^2$ of fresh chicken manure |
| C. Solartex 800 + Biof. | Black Solartex 800 l/ha in combination with3 kg/m$^2$ of fresh chicken manure |
| D. Solartex 500 | Black Solartex 500 l/ha |
| E. Solartex 800 | Black Solartex 800 l/ha |
| F. Solartex 1100 | Black Solartex 1,100 l/ha |
| G. Solartex 500 + MS 750 | Black Solartex 500 l/ha with Metam Sodium applied by sprinklers 750 l/ha |
| H. Solartex 800 + MS 750 | Black Solartex 800 l/ha with Metam Sodium applied by sprinklers 750 l/ha |
| I. Solartex 1100 + MS 750 | Black Solartex 1,100 l/ha with Metam Sodium applied by sprinklers 750 l/ha |

Fumigant treatments were applied on July 10th 2003, using one mounted implement with conventional tank for phytosanitary applications connected to a bar of treatments with several nozzles. Solartex® was diluted in water 2:1 w/w (product/water). Data-loggers to record soil temperature were installed at 10 cm deep in treatments A, B and E. MS was applied by mean of micro-sprinklers in treatments G, H and I on July 24th 2003. Soil treatments finished on August 22nd 2003. Layers of Solartex® were removed (incorporated on the soil) raking with a disk-harrow. Conventional cultivation system under small plastic tunnels was followed.

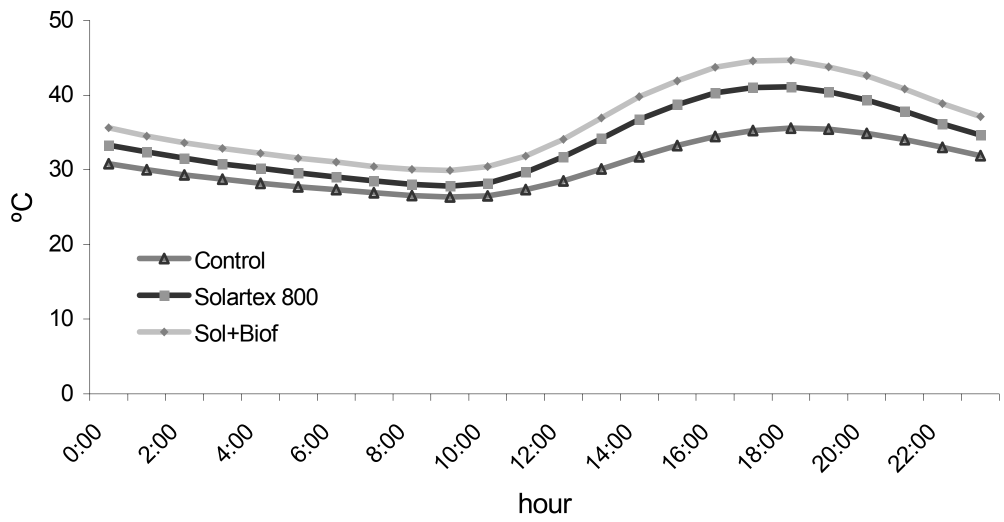
Planting with cultivar 'Camarosa' was done on October 14th 2003 after building and mulching the beds with black LDPE. Harvesting period took place from January 7th to May 18th 2004 (22 harvests). Weeding on the top of beds was recorded; in particular presence of common purslane (*Portulaca oleracea)* was smaller in treatments G, H, I (all of them with additional MS application) and B, C (biofumigated).

To estimate plant vigour, ten plants per treatment were selected at the beginning of the cultivation season. Equatorial plant diameter was recorded five times (end of December to end of April).

## RESULTS

The average soil temperatures recorded daily are shown in Figure 1. Treatment E (Solartex 800) showed slightly lower soil temperature than treatment B (Sol+Biof) and higher than treatment A (Untreated control).

Figure 1: Average soil temperatures (ºC) recorded 10 cm deep for LDPE (Sol+Biof) and Solartex.




Soil samples taken before and after the application of soil treatments and plant samples recorded during the growing season did not show any kind of soil-borne strawberry pathogens.

Treatment B (Sol.+Biof.) gave the biggest plant diameters (Table 2) during the first part of the growing season (December-February). However, in treatments H and I (Solartex in combination with MS) plant diameters were similar in the medium-final part of the growing season (March-April).

Table 2: Strawberry plant diameter (cm) using LDPE film and sprayable polymers (Solartex) as solarization agents

| Treatment | Dec. 26 | Jan. 20 | Feb. 25 | Mar. 29 | Apr. 23 |
|---|---|---|---|---|---|
| A. Untreated | 19.2 | 20.3 | 22.6 | 24.8 | 25.6 |
| B. LDPE film + Biof | 23.3 | 24.8 | 25.9 | 27.1 | 28.3 |
| C. Solartex 800 + Biof. | 19.8 | 21.2 | 23.1 | 25.9 | 26.1 |
| D. Solartex 500 | 15.8 | 19.1 | 22.0 | 24.1 | 26.3 |
| E. Solartex 800 | 20.4 | 21.4 | 23.3 | 25.2 | 26.0 |
| F. Solartex 1100 | 17.3 | 19.5 | 21.2 | 24.5 | 24.9 |
| G. Solartex 500 + MS 750 | 17.0 | 19.5 | 21.2 | 24.5 | 25.7 |
| H. Solartex 800 + MS 750 | 20.1 | 22.4 | 23.5 | 27.6 | 27.0 |
| I. Solartex 1100 + MS 750 | 17.5 | 19.2 | 23.0 | 28.5 | 28.8 |

The yields (g per plant) are presented in Table 3. Early commercial yield (harvested up to March 31st 2004) of treatment B (Sol+Biof) and C (Solartex 800 + Biof) were the highest followed by the treatments with MS: G (Solartex 500 + MS 750) and H (Solartex 800 + MS 750).

Table 3: Commercial yield (g/plant) and other agronomic traits.

| | Early yield (up to March 31st 2004) | | | Total yield (up to May 18th 2004) | | |
|---|---|---|---|---|---|---|
| Treatment | Production | % 2nd cat. | Fruit weight(1) | Production | % 2nd cat. | Fruit weight(1) |
| A. Untreated | 193.3 | 13.5 | 30.1 | 492.0 | 13.8 | 29.5 |
| B. LDPE + Biof. | 275.5 | 20.8 | 32.0 | 613.1 | 22.6 | 29.6 |
| C. Solartex 800 + Biof. | 263.2 | 18.0 | 27.1 | 549.5 | 16.8 | 26.9 |
| D. Solartex 500 | 240.6 | 17.1 | 29.8 | 552.0 | 16.1 | 28.3 |
| E. Solartex 800 | 229.0 | 22.1 | 29.2 | 476.2 | 21.4 | 28.1 |
| F. Solartex 1100 | 215.3 | 18.1 | 28.9 | 520.9 | 16.8 | 27.3 |
| G. Solartex 500 + MS 750 | 252.9 | 15.2 | 32.2 | 623.7 | 14.7 | 29.9 |
| H. Solartex 800 + MS 750 | 252.8 | 18.5 | 34.2 | 607.5 | 17.5 | 31.8 |
| I. Solartex 1100 + MS 750 | 232.2 | 19.0 | 32.4 | 602.9 | 15.8 | 30.2 |

(1) g/fruit

The lowest early yields were observed in treatments with Solartex alone (D, E, F) and in untreated control (A). Regarding the total commercial yield (harvested up to May 18th 2004), treatment B (Sol+Biof) and G, H, I (all of them with additional MS application) were the most productive. However, treatment C (Solartex 800 + Biof) retreated in comparison with its early commercial yield results. Fruit size (in this case fruit weight) showed a quite similar pattern to the observed for commercial yield (Table 3).

The estimate of costs for each treatment are: B (Sol.+Biof.), €850 /ha; C (Solartex 800 + Biof.),€820/ha; D (Solartex 500), €510/ha; E (Solartex 800),€820/ha; F (Solartex 1100), €1,120/ha; G (Solartex 500 + MS 750), €1,070/ha; H (Solartex 800 + MS 750), €1,380/ha; I (Solartex 1100 + MS 750), €1,680/ha. The cost for standard MB:PIC shank-application is €1,120/ha

## DISCUSSION

As these trials in 2003 showed the potential of polymers to replace LDPE film, a new series of experiments have recently started on the Farm using Solartex 800 l/ha + Biof. (3 kg/$m^2$ fresh chicken manure), Solartex 800 l/ha, Solartex 800 l/ha + MS 800 l/ha, standard Sol.+Biof., solarization just on pre-formed beds with black LDPE + Biof., and untreated control. Trials and field scale demonstrations of polymers will be carried out using ‘Camarosa’ and ‘Ventana’ in two locations Polymers and Biof will be compared with the most promising chemical alternatives to MB (Telopic®, DMDS+pic®, and Propozone®).

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# STRAWBERRY NURSERIES: SUMMARIES OF ALTERNATIVES TO METHYL BROMIDE FUMIGATION AND TRIALS IN DIFFERENT GEOGRAPHIC REGIONS

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## ABSTRACT

A limited number of trials have been conducted worldwide to find alternatives to methyl bromide (MB) for use in the strawberry nursery industry. These trials have shown inconsistent results probably because of the climatic conditions unfavourable to non-MB fumigants that prevent compliance with strict sanitation requirements to avoid spreading soillborne pests and disease to the strawberry fruit industry. Consequently, many strawberry nursery industries from around the world have applied for critical use exemptions from the 2005 MB phase-out because they consider that there are no alternatives available. Despite these difficulties, 1,3-dichloropropene/chloropicrin (PIC) mixture, and PIC alone, have significantly reduced soilborne pathogens to a level equivalent to MB/PIC. Other products such as ethanedinitrile and methyl iodide/PIC hold promise. Containerised transplants produced in soil-less media ('plug plants') have the potential to decrease reliance on soil fumigants but their broad-scale adoption for long season production is proving difficult. Further studies are required to determine: (a) control with depth for the full range of root pathogens and weeds that affect strawberry nursery runner plants; (b) effects of alternatives on the subsequent yields of different strawberry varieties; (c) the impact of alternatives on disease threshold levels and the fruit-yielding potential of transplants; and (d) issues relating to the scale-up and long-term use of alternatives.

**Keywords:** methyl bromide, strawberry nursery, Montreal Protocol, soil disinfestation, plug plants, transplants, 1,3-dichloropropene, chloropicrin, soilborne pathogens,

## INTRODUCTION

Most strawberry nursery plants are produced under phytosanitary controls or 'certification' programmes where regulations generally require that soils be disinfested. In the USA, substantial proportions of nursery plants have also been exempted from the methyl bromide (MB) phase-out under quarantine and pre-shipment guidelines (QPS) to meet local regulatory and export requirements.

Effective soil disinfestation is extremely critical for the strawberry nursery industry as it ensures the production of 'certified' transplants that minimise the spread of diseases to the strawberry fruit industry. MB/chloropicrin (PIC) mixtures have been adopted throughout the world because of their broad-spectrum control of pathogens and weeds, their ability to induce an 'increased growth response' in crops and their ease of use. The most prominent pathogens controlled include those that cause major loss in the fruit industry, viz; *Phytophthora* spp., *Verticillium dahliae, Pythium* spp., *Rhizoctonia* spp., *Cylindrocarpon* spp. *and Fusarium* spp. (Duniway 2002).

Finding alternatives to MB in the strawberry nursery industry worldwide is proving more difficult than the strawberry fruit industry because of the complex number of factors that need to be taken into account when adopting an alternative. The volatile nature of formulations of MB/PIC mixtures provides growers with an easy and reliable method of fumigation in a wide range of climatic conditions, soil types and cropping conditions and this has ensured that strawberry nursery and fruit industries have remained highly productive. This paper discusses some of the issues that need to be overcome to increase the rate of adoption of alternatives in strawberry nursery industries.

## INDUSTRY REQUIREMENT FOR METHYL BROMIDE

The strawberry nursery industry relies on rigorous screening of varieties for high health, which includes virus testing of nuclear material and routine soil disinfestation. In Australia, any soil disinfestant can be used, but

MB/PIC mixtures have been traditionally applied. At present three of the four generations in many regions (eg. nuclear-foundation-mother-runners in Australia) are grown in disinfested soils to ensure that disease does not increase progressively through the multiplication process. In spite of this, nursery plants in several countries have been shown to contain low levels of specific pathogens (eg. *P. cactorum*) even with the use of MB/PIC mixtures (DeCal *et al.* 2004). Most of the nuclear stock is produced in hydroponic substrate systems, and in some countries with smaller crop production there is potential for the next generation foundation stock to also be produced in hydroponics. To date only a small proportion of mother stock and runners have been produced in substrates in the major strawberry production regions of the world (USA, Spain, Italy).

**SOILLESS CULTURE/HYDROPONICS - PLUG PLANTS**

Strawberry 'plug plants' (containerised transplants produced in soil-less media) offer the best opportunity for the nursery industry to reduce its reliance on chemical fumigation. Plugs have the advantage that they can be 'certified' disease-free and can yield fruit 2 to 3 weeks earlier than bare-rooted runners produced in soil (Sances 2001).

In 2001, 3 million plug plants of the varieties 'Camarosa' and 'Ventura' were produced for planting in central and southern California. Future expansion in the subsequent years was affected by widespread outbreaks of *Colletotrichum acutatum* which spread because strict hygiene protocols were not maintained (Ajwa *et al.* 2004; C. Winterbottom, *pers com* 2003). The cost of a plug plant compared with a standard bare-rooted runner plant in the USA in 2001 was c. US$ 0.17 - 0.21 and $0.08, respectively. Although plug plants cost 2-3 times more, they are economical for short season production where market windows offset the production cost. Several disadvantages of plugs compared with bare-rooted runners are that they require extra handling and transport costs, and the meristem production and fruiting capability is not yet fully understood (F. Sances *pers. com.* 2003).

Further effort should be directed to the development of successful plug plant systems to replace or offset the need for MB as these systems can offer further advantages in crop production such as short production cycles, mechanised transplanting, reduced water requirement, improved plant survival and early production (Durner *et al.* 2002).

Other non-chemical methods of soil disinfestation are presently considered impractical in the environments where runners are grown. The physiological requirement for chilling prevents solarisation being suitable in nurseries because of the cool climatic zones where nurseries are located worldwide. Biofumigant crops (Brassicas) have been shown to be beneficial in rotation with strawberries, but do not provide sufficient eradication of pathogens (Mattner *et al.* 2004). 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 control.

**ALTERNATIVE FUMIGANTS**

The strawberry nursery industries' need for complete elimination of diseases, that is eradication of pathogens and weeds, means that in the short term large-scale production is likely to continue to rely on chemical disinfestation.

The most promising chemical alternative in strawberry fruit production 1,3-D/PIC has not been as effective for strawberry runner production because, although results have given promising disease control, yields of runners have been variable and weeds have not been controlled as effectively as with MB/PIC mixtures (Table 1).

In Australia, Mattner *et al.* (2004) found that fumigation of nursery beds with MB (MB/PIC 70:30, 500 kg/ha) controlled 99.5% of all weeds (mostly *Poa annua* and *Spergula arvensis*). In comparison, 1,3-D/PIC (65:35, 500kg/ha) only controlled 73.3% of weeds. In a separate study, fumigation with 1,3-D/PIC stimulated the germination of the weed *Chenopodium murales* in runner beds compared with MB by breaking its dormancy (Donohoe *et al*. 2001).

Table 1. Relative effect of alternatives compared with methyl bromide on strawberry nursery yield (numbers of runners per metre of row) in Australia.

| Treatment | MB/Pic | Unt | TC35 | Pic | MS and Pic | MI | *EDN* |
|---|---|---|---|---|---|---|---|
| **No of studies** | 8 | 6 | 8 | 8 | 2 | 1 | 1 |
| **Range** | 100 | 59-103 | 75**-105 | 62-109 | 82-101 | 122 | 107 |
| **Average** | **100** | **73** | **91** | **89** | **91** | **122** | **107** |

****-** TC35 was phytotoxic
MB/PIC = Methyl bromide/chloropicrin (70:30); TC35 = 1,3-D/chloropicrin (65:35); PIC = chloropicrin; MS/PIC = Metham sodium followed by chloropicrin; MI = Methyl iodide/chloropicrin (30:70); EDN = ethanedinitrile

Over a 6 year period in Australia, 1,3-D/PIC, PIC alone and metham followed by PIC have given variable yield results (Table 1), but good disease control (Figure 1; Mattner *et al.* 2004) compared with MB for runner production.

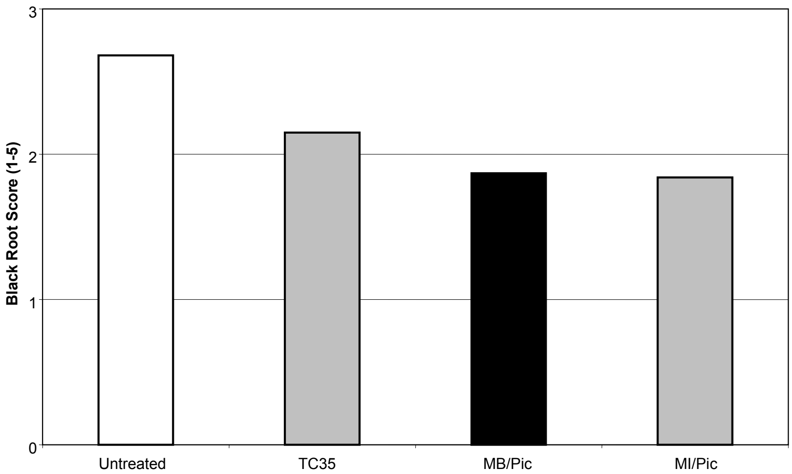


Figure 1: Relative effect of methyl bromide and alternatives for control of black root rot in a strawberry nursery trial in Australia**.**

Similar results have been observed in other countries. For example, in a 3-year trial in the USA, Gordon *et al.* (1999) found that MB (MB/PIC 67:33, 390 kg/ha), chloropicrin (280 kg/ha) and 1,3-D/PIC (65:35, 448 kg/ha) were equally effective at controlling *Verticillium dahliae* in nursery beds. Fumigation reduced *V. dahliae* microsclerotia populations from 20 ms/g soil to <1 ms/g soil and the incidence of Verticillium wilt in strawberry runners (varieties 'Selva' and 'Camarosa') from 87% to 0%. Yet, strawberries grown in 1,3-D/PIC and chloropicrin-treated plots produced 23% fewer runners than plants in MB-treated plots. Similarly in Spain, Lopez-Aranda (1999) found that fumigation with MB (MB/PIC 67:33, 400 kg/ha), 1,3-D/PIC (83:17, 400 kg/ha), 1,3-D/PIC (65:35, 350 kg/ha) and chloropicrin (400 kg/ha) effectively controlled *Phytophthora cactorum* in nursery beds. Fumigation with MB and 1,3-D/PIC (83:17) increased yields of 'Camarosa' strawberries by up to 300% compared with untreated plots. However, 1,3-D/PIC (65:35) and chloropicrin were less effective, increasing yields by up to 195%.

One reason for the variable results of alternatives in the nursery industry is that most alternatives have higher boiling points and lower vapour pressures than MB, and therefore do not move through soil profiles as readily as MB. This factor is often exacerbated in regions where strawberry nursery transplants are grown because climatic conditions foun in the strawberry nurseries consisting of low temperatures due to the high elevations, combined with high soil moisture content, impede the performance of the fumigant. In Australia this has led to increased plant-back requirements for some alternatives in the nursery industry and incidences of crop phytotoxicity (Mattner *et al.* 2003).

Preliminary results in Australia with ethanedinitrile, together with a number of trials in the USA with methyl iodide/PIC, indicate that these products may offer better results than previous alternatives evaluated because their physical properties are more similar to MB (Mattner *et al.* 2004).

## FUTURE CHALLENGES

Whilst the commercially available alternatives above have given promising results in terms of pathogen control, more work is required to confirm that alternatives provide the same consistent control that has been provided by MB/PIC. Only a limited number of studies have benchmarked the comparative performance of alternatives against MB/PIC for the major target pathogens of strawberries (eg. *Phytophthora, Pythium, Rhizoctonia, Fusarium, Verticillium spp.*) and also weeds.

Further comparative studies on specific pathogen control between MB/PIC and alternative fumigants are required to confirm their effect on the wide range of root pathogens that affect strawberry plants. Studies are also required to confirm their performance for control of the most common weeds in nursery production regions and to determine consistent effects of alternatives on the yields of different varieties over a number of years. Also, more studies are needed to verify if runners produced under different fumigant regimes meet the disease thresholds set by regulations in several countries for transplanting into fruiting fields.

The strawberry nursery industry should not be complacent and rely on exemptions for 'Critical Use' to support the industry for substantial periods after 2005. Even though some CUE's have been granted, future markets are forever demanding more 'environmentally friendly' production practices and no industry will be truly sustainable until such practices are implemented. The strawberry nursery industry has two options: It can switch to the next best fumigant alternative, or invest in alternative systems such as the development of soil-less production systems that promote environmental sustainability.

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# ALTERNATIVES TO METHYL BROMIDE ADOPTED FOR CUCURBIT PRODUCTION IN PROJECTS FUNDED BY THE MONTREAL PROTOCOL

# MAIN ALTERNATIVES ADOPTED IN PROJECTS FUNDED BY THE MONTREAL PROTOCOL FOR THE PRODUCTION OF TOMATO, PEPPER AND EGGPLANT IN CLIMATES SIMILAR TO THE MEDITERRANEAN REGION

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## ABSTRACT

UNIDO is executing 29 methyl bromide (MB) phase out projects in 25 countries in the horticultural sector. The main crops are melon, watermelon, tomato, cucumber, eggplant and sweet pepper. The alternatives showing the best results in large-scale farming are 1.3-Dicloropropene + chloropicrin, and grafting. Small-scale farmers are trained in replacing MB by the use of grafting, biosolarization or biofumigation, metam sodium and 1.3-Dicloropropene + chloropicrin. UNIDO's goal in implementing alternatives is to maintain production at the same level as when MB is used without increasing the overall cost. UNIDO also aims to adapt the alternatives to the requirements of the producer thus potentially allowing the producer to shift from one alternative to the other depending on the pest-disease complex and the management system.

**Keywords:** grafting, alternatives cost comparison, cucurbits, tomato, pepper, alternatives to methyl bromide.

## INTRODUCTION

UNIDO is one of four agencies that is responsible for implementing 29 methyl bromide (MB) phase out projects in 25 countries. Of all the agencies, UNIDO has the most projects and the largest single budget for the phase out of MB in developing countries. The total budget currently approved is about US$ 42 million. The phase out target is almost 8,200 ODS tonnes.

As developing countries are scheduled to decrease their use of MB by 20% in 2005 under the requirements of the Montreal Protocol, compared to their average base level consumption in 1995-1998, a number of projects have been approved to assist countries to achieve this 20% reduction target. In the near future, further new projects will be implemented to meet the 2005 phase out commitment for MB in developing countries.

Due to the wide range of climatic conditions, farms size, farmer skills and other factors coupled with the constant development of MB alternatives, we have to follow closely farmers' needs to ensure the long-term sustainability of the alternatives proposed.

## CUCURBITS

Melon is the most predominant cucurbit crop in UNIDO`s list of project with watermelon and cucumber being grown in less volume. Melon and watermelon are grown in Central America. Cucumber is grown in the Mediterranean area and Romania.

A typical melon farm covers 1,500 Ha. The farming system is relatively sophisticated with a high level of dependence on MB for soil disinfestation.

The alternatives that have the greatest adoption rates and the confidence of farmers are grafting and 1.3-dicloropropene + chloropicrin (1,3D / PIC). Biosolarization, impermeable mulching film, resistant varieties and new fumigants show potential for the future. UNIDO encourages "good agronomic practices" such as the use of organic matter, water, fertilizer and pest management in order to promote successful control of soil borne pests.

After one year working at commercial scale with grafting and 1,3D / PIC, UNIDO estimates the following costs:

Table 1: Melon seedling, US$ per Ha (Central America)

| SEEDLING COST US$/HA | REGULAR | GRAFTED |
|---|---|---|
| **TOTAL FOR 2 CYCLES** | **$541.93** | **$1,221.12** |
| Number of seedling/Ha, for 2 cycles | 22,000 | 17,600 |
| Seedling unit cost<br>Regular seedling: 242 cell/Tray, 34 x 67 cm<br>Grafted seedling: 128 cell/Tray, 34 x 67 cm | 0.02463 | 0.06938 |

Table 2: Soil treatment: US$ per Ha, melon Central America

| Cost<br>US$/Ha | Methyl bromide + Normal film + Normal seedling | No soil treatment + Grafted seedling | Methyl bromide + VIF + Normal seedling | 1,3-D / PIC + Normal film + Normal seedling | 1,3-D / PIC + VIF + Normal seedling |
|---|---|---|---|---|---|
| **Total** | **$1,648** | **$1,677** | **$1,844** | **$1,948** | **$2,024** |
| **Seedling** | **$542** | **$1,221** | **$542** | **$542** | **$542** |
| **Fumigant** | **$650** | **$0** | **$390** | **$950** | **$570** |
| Dosage Kg/Ha | 250 | 0 | 150 | 250 | 150 |
| US$/Kg | 2.6 | 0.0 | 2.6 | 3.8 | 3.8 |
| **Plastic film** | **$456** | **$456** | **$912** | **$456** | **$912** |
| $m^2$/Ha | 7,600 | 7,600 | 7,600 | 7,600 | 7,600 |
| US$/$m^2$ | $0.06 | $0.06 | $0.12 | $0.06 | $0.12 |

UNIDO has not detected any differences in yield between MB-treated and crops treated with the alternatives, even with considerable effort in this area to measure yield differences. It appears to UNIDO that MB technology has reached its pick of efficiency while other chemicals and grafting have yet to reach their full potential. Grafting requires further effort to establish the best nursery and field management. UNIDO is confident that with further improvements in the use of alternatives to MB it is likely that both yield and fruit quality will increase over time.

In Honduras and Guatemala, in order to achieve the 20% reduction target required of developing countries by the Montreal Protocol by 1 January 2005, UNIDO has installed 60,000 $m^2$ of nurseries for grafted seedling production. At full capacity these nurseries can produce 30 million grafted seedlings per crop season (8 weeks window), equivalent to 3,400 Ha and employs at least 1,000 people. The total melon area in Honduras and Guatemala is about 9,000 Ha. Therefore, our seeding production capacity covers about 30% of the total requirements. We believe that the answer will be a mix of different alternatives,. In developing and implementing a range of alternatives, it will become more important to match the range of alternatives to the crop management system in order to maximise yield and quality.

In the Mediterranean area, grafted melon, watermelon and cucumber are widely used and the demand is constantly growing. UNIDO is implementing several projects in the area. The most advanced project is the one in Romania where grafted cucumber is showing a big potential and is very much appreciated by farmers. Grafting, biosolarization and/or metam sodium and/or Dazomet can control the entire range of soil borne disease and weeds previously controlled by MB. A pilot nursery unit of 1,500 $m^2$ with a capacity of 60,000 seedlings per week will be full operational in October 2004 in Bucharest.

## TOMATO, PEPPER AND EGGPLANT

UNIDO projects involved in the production of tomato, pepper and eggplant concern mostly producers that have small holdings (0.5÷1 Ha). Due to the small land area, MB alternatives can require high-input and intensive crop management. To this end, farmers have recognized the value of biofumigation, biosolarization, grafting and the fumigants metam sodium, and 1,3-D / PIC because they can achieve yield and costs comparable to MB.

UNIDO believes that improving crop management and yield is as important as seeking effective chemical or biological alternatives. In Guatemala, for example, in the course of only one year UNIDO improved soil preparation and crop management practices while at the same time replacing MB with metam sodium. The combination resulted in a doubling of tomato yield. It is difficult to say if the improvement was due to metam sodium or to the new crop management. However, whatever the cause, the farmers remain very happy with the increased production.

Grafting requires a suitable nursery installation to produce high quality grafted seedling. High quality planting material is essential for the success of grafting. In Romania, UNIDO is installing a pilot nursery unit of 1,500 $m^2$ with a capacity of 60,000 seedlings per week. The nursery will produce seedlings for a small group of tomato and cucumber producers. A number of rootstocks are already available, inter-specific tomato for tomato and *Solanum torvum* for eggplant. Both rootstocks have helpful level of resistance and tolerance to the main soil borne pathogens. A tomato variety, resistant to *Xanthomonas* sp., is used in Guatemala as rootstock for a tomato variety with no tolerance. As MB is a weak bactericide it is of no help. In Central America and Mediterranean area, *Solanum torvum* is the common rootstock used for eggplant. It is excellent against nematodes, Fusarium and corky root. Official data will be available in one-year's time.

It terms of cost, it is difficult to generalize from a range of trials as inputs are often not comparable. In addition, labour cost and locally-available natural resources are unlikely to be quantified in developing countries.

## CONCLUSIONS

UNIDO`s experience shows that MB alternatives exist. UNIDO`s effort is focused in two complementary objectives: firstly, providing equipment that is generally unavailable for small-scale as well large-scale farmers; and, secondly, looking at and ways to improve the entire production process.

We have seen that the farmer is willing to invest his own resources in the technology development once the new technology is shown to have potential. This process gives farmers the opportunity to learn new methods and to realise new market opportunities where tight protocols are in force to reduce chemical residues.

When UNIDO approaches a new farmer or a new sector we are unlikely to look just at yield increase. We believe that first we must make sure the alternative can produce the same yield at the same cost. In doing so we can be assured that the alternative is sustainable. If the farmer is able to create a better yield this is an added value that belongs to the skill of the farmer.

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For UNIDO`s project documents and project reports, contact project manager a.amadio@unido.org

# USE OF GRAFTED CUCURBITS IN THE MEDITERRANEAN REGION AS AN ALTERNATIVE TO METHYL BROMIDE

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## ABSTRACT

In the Mediterranean Region, grafting is one of the most commonly used alternatives to methyl bromide (MB) treatment in crops of cucurbits. Watermelon, melon and cucumber can be grafted onto several species, but the most commonly used rootstocks are hybrids of *Cucurbita* (*C. maxima* x *C. moschata*). In some countries the grafting method that is most frequently employed is “tongue approach” and in others, “splice grafting”. This technique controls a wide range of pathogens, but is used fundamentally in watermelon, to avoid *Fusarium oxysporum f. sp niveum*; in melon *F. oxysporum f.sp. melonis* and *Monosporascus cannonballus*; and in cucumber *Phomopsis sclerotioides*. The use of grafting techniques in cucurbits crops is widespread in France (1000 Ha of melon), Morocco, Italy (20 million watermelon plants and 5-6 million melon), Spain (30 million watermelon plants) and is spreading in Jordan (50 Ha) and Israel. The cost of grafting is much lower than the cost of MB-fumigation of soil.

**Keywords:** Grafting, watermelon, melon, cucumber, methyl bromide, alterantive, pathogens

## INTRODUCTION

Grafting is used successfully, as a method to prevent diseases in melon, cucumber and watermelon crops.

### Rootstocks

Several species of the same family (*Cucurbitaceae*) can be used as rootstock. This should be resistant to the disease that it is being used to prevent; have good compatibility with the scion; give vigour and strength; possess good conditions for the grafting to be carried out; and not modify the fruit quality unfavourably. (Miguel,A.1997)
The species that are used as rootstock in cucurbitaceae are:

| | Melon | Cucumber | Watermelon |
|---|---|---|---|
| *Cucumis melo* | + | - | - |
| *Citrullus lanatus.* | - | - | + |
| *Cucurbita moschata* | - | - | + |
| *Cucurbita ficifolia* | - | + | - |
| *C. máxima x C.moschata* | + | + | + |
| *Lagenaria siceraria* | - | - | + |
| *Benincasa cerifera* | + | - | - |

The watermelon displays, in general, fewer problems of incompatibility, with several species of the same family as the melon. There are even important differences of compatibility with certain species between the different types or botanical varieties of melon.

### Grafting methods

Several grafting methods (Lee, J.M. 2003) are used.

Tongue approach grafting: With this method, during the union phase of grafting the two plants (the rootstock and the scion) conserve their root systems.

Insertion grafting: Once joined, the union is stronger. There is no need to cut the stem of the scion variety.

Splice grafting: It has the same advantages as the previous one and seems more easily automated.

The tongue approach method is, at the moment, the most commonly used, because it is the safest. In these last two methods, during the phase of union, the variety is without roots. This method requires the control of temperature and relative humidity to avoid the scion dehydrating before the union has been established with the rootstock.

Although in Spain (Valencia) grafting began almost 30 years ago on the horticultural farms, it did not become popular until it was developed at the level of specialized nurseries. In these companies, grafting is carried out by trained personnel who work in this activity for long periods during the year. Now they are beginning to use robots to improve labour efficiency.

**Pathogens controlled by Grafting**

| | Melon | **Cucumber** | Watermelon |
|---|---|---|---|
| *Fusarium oxysporum melonis* * | + | - | - |
| *F. oxysporum f.sp. niveum* * | - | - | + |
| *F. oxysporum f.sp. cucumerinum* * | - | + | - |
| *Phomopsis sclerotiodes* | - | + | - |
| *Monosporascus cannonballu*s | + | - | + |
| Melon Necrotic Spot Virus (MNSV) | + | - | + |
| *Meloidgyne* sp. | + | + | + |

* They are not strictly specific, thus some authors (Gerlagh and Blok, 1998) consider them varieties of *F. oxysporum f. sp.cucurbitacearum.*

The importance of the different pathogens varies greatly in the different Mediterranean Regions. This is not the case with FON, which is the most important pathogen affecting watermelon in all regions where it is habitually cultivated (Brayford 1992).

## USE OF GRAFTING IN DIFFERENT COUNTRIES IN THE MEDITERRANEAN REGION

### France

In France, grafting has been used for long time (Louvet 1974) as a method to prevent fusarium wilt (*F. oxysporum f.sp. melonis*) of the melon. The creation of resistant varieties to the strains 0, 1 and 2 have never been enough to avoid the disease, since new strains have appeared (FOM strain 1.2) of the pathogen, that are able to overcome the resistances. The most commonly used rootstock for many years has been *Benincasa cerifera* but it has been substituted by others of the type *C. maxima x C. moschata* (Ginoux 1996; Fritsch 2002).

Melon grafting contributes improved strength and better behavioural characteristics of the plant when soil temperatures are low, but it is necessary to graft high quality varieties that are not very sensitive to "vitrescence" (Taussig 1996).

Grafted melon is produced on about 1000 Ha. and is particularly important for early production (P. Erard *pers. comm.* 2004). In greenhouse cucumber the worst soil pathogen has been and continues to be *Phomopsis sclerotiodes*, which had to be controlled with disinfection using MB. Grafting onto *C. ficifolia* or onto the interspecific hybrid *C. maxima x C. moschata* is as effective. Grafted cucumber is hardly 3% of the total (P. Erard *pers. comm.* 2004).

**Italy**

The most important pathogen affecting melons is *F. oxysporum f.sp. melonis* (Cartia 2002), besides the nematodes (*Meloidogyne spp.*) (D'Addabo 2002). In the beginning, as in France, melon was grafted onto *Benincasa* (Ruggieri 1971), *C.ficifolia* or resistant varieties of melon (Trentini & Maioli 1984).

In Sardinia the first experiments of grafting Cucurbitaceae were carried out at the beginning of the 1990s. By 2000, the grafted plants of melon covered more than 30 ha. and watermelon around 90 ha (Siddu 2000).

It is believed that in Italy 5-6 million melon plants are grafted annually, most of them onto hybrid *Cucurbita*, but also some onto melon resistant to *Fusarium*. Grafting has spread more in watermelon cultivation. About 20 million plants are grafted a year, almost all them onto hybrid *Cucurbita*. In cucumber this technique has not been developed yet. The most commonly used grafting method in cucurbitaceae is splice grafting (*Pers.comm.* A. Amadio 2004).

**Greece**

Experiments have been carried out of melon grafting with different rootstocks (hybrids of *Cucurbita* and with *C. moschata* (Traka-Mavrona 2000). In cucumber is important for controlling fusarium wilt, caused by *F. oxysporum f sp. radicis-cucumerinum*. Several tested rootstocks enable the disease to be controlled and they are a good alternative to the use of MB (Pavlou 2002).

**Turkey**

Melon and watermelon cultivation occupy a very important surface area in Turkey. The fusarium wilt (several species *of F. oxysporum f. sp. melonis* and *F. oxysporum f. sp. niveum*) represents the most serious disease in both species (Ozturk *et al.* 2002).

**Israel**

Grafting has not been used in Israel, unlike other countries in the Mediterranean Basin, due to the availability of MB. This situation is changing and, in watermelon, the practice of grafting is spreading. The watermelon has a good compatibility to *Cucurbita* and grafting allows the pathogens, including *Monosporascus,* to be controlled. Both *Cucurbita* and *Lagenaria* are hosts of *Monosporascus*, but their strong root system allows them to complete the growing cycle. Grafting can be an effective method of control although, if there is a certain degree of colonization, it should be combined with other techniques so that the pathogen population does not grow too much. The damage caused by *Meloidogyne* in melon is much smaller in grafted plants than in plants without grafting. In some varieties there are problems of incompatibility (Cohen *et al.* 2000).

According to Jewish law, it is forbidden to graft two different plant species. Melon, watermelon and pumpkin are considered in the popular taxonomy, a single class, thus this prohibition should not be applicable (Kislu & Katzir 2000).

**Jordan**

The technique of grafting was introduced by the “MB Phase Out Project” in 2002. Several plant nurseries have received training to produce grafted plants and, in 2004 they have begun to use this technique commercially. In Jordan, 40 ha of grafted watermelon have been planted which represent 20% of the watermelon that is disinfected with MB. Ten ha of grafted melon were planted in 2004 and 0.5 ha of cucumber. In both species, the technique is still just starting. In all cases, the grafting used is tongue approach and the rootstock is of the type *C. maxima x C.moschata*, although in cucumber *Sycios angulatus* has also been used. The cost of grafting is $ 0.25-0.35 per plant, plus the price of the seed of the scion variety. The grafting technique will certainly spread quickly, especially in watermelon (*Pers. comm.* F.M. Al-Zub 2004).

**Morocco and Tunisia**

Grafting in melon and watermelon is widespread in Morocco to control *Fusarium* and *Verticillium* wilt. As the rootstocks used are not resistant to nematodes, grafting is used together with nematicide treatments (1,3-dichloropropene; 1,3-dichloropropene + Chloropicrin or Metam sodium) (*Pers. comm*. M. Besri 2004).

In a study carried out in Tunisia from 1989 to 1992, melons grafted onto *C. maxima x C. moschata* were earlier and more productive, resistant to *Fusarium* wilt and more tolerant to nematodes than the ungrafted melons (Jebari 1994).

**Spain**

The most important melon pathogens in Spain are *Monosporascus cannonballus* and MNSV. The former affects mainly open air cultivation or with simple protection (plastic mulch, small tunnel, floating cover) in Murcia, Valencia or Castilla la Mancha, and the latter (MNSV), greenhouse cultivation in Almería. The incidence of *M. cannonballus* varies from one year to another and as crop rotation is practised to a certain degree, avoiding successively melon in the same plots, results in it not being an important disease.

MNSV, which caused a true disaster in the greenhouse of Almeria, is no longer problematic when melon is alternated with other crops or resistant varieties are used. Contrary to other countries, FOM, although it has been detected, does not constitute an important blight.

Numerous experiments have been carried out with different rootstocks in order to control the pathogens affecting ground melon. The Spanish type varieties (*P. sapo*, Amarillo, Rochet) do not have good affinity with *Benincasa cerifera* nor is it particularly good with those of the type *C. maxima x C. moschata*. The latter ones usually achieve better union with varietal types Galia or Cantaloup and also with *C, melo var. flexuosus* (alficoz), but because Galia or Cantaloup have few problems with respect to collapse and the increase in fruit size induced by grafting makes it unrecommendable, only a low level of Alficoz production and some Cantaloup production is carried out using grafted melon.

The cultivation of cucumber is only of importance in Almería, where crop rotation together with the system of using sand-covered soil and periodic disinfections with Metam sodium or 1,3-dichloropropene, mean soil problems are not of particular importance. Another smaller area of cucumber cultivation takes place in greenhouses near Madrid. There the main problem is the gall nematode (*M. incognita*). Experiments with grafting have always provided encouraging results, although the rootstocks used are not resistent to this pest (*Pers. comm.* P. Hoyos 2001).

In watermelon the main problem, in the areas where the cultivation is repeated is FON, although other pathogens have been detected, such as *Monosporascus cannonballus, Verticillium. dahliae, Rhizoctonia solani* or *Meloidogyne incognita,* also contribute to deterioration of the plants. The only solution in these areas where cultivation is repeated was disinfection with MB. Years ago, before it was banned, MB was substituted by grafting, because this was cheaper, safer and more effective. (Miguel, A. et als 2004). At present, some 30 million watermelon plants are grafted annually, covering a surface area of around 12000 ha, mainly in countries where the crop is repeated with certain intensity (Almería, Valencia, Murcia).

## COST COMPARISONS WITH METHYL BROMIDE

Costs of watermelon production with grafted plants and localized irrigation (Valencia) is shown as follows.

| | Activity | Euros/Ha |
|---|---|---|
| | Irrigation | 217 |
| | Fertilizer (including organic) | 713 |
| | Pesticides | 240 |
| | Triploid plants | 1020 |
| | Diploid plants | 330 |
| | Plastic | 57 |
| Total raw materials | | 2577 |
| | Labour | 3270 |
| **Total variable costs** | | **5847** |
| Fixed costs | | 225 |
| **Total costs** | | **6072** |

| | |
|---|---|
| Production | 51,400 kg/Ha without seeds |
| Production | 25,600 kg/Ha with seeds |
| The cost of the **grafted** plants are: 2000 plants/Ha x €0'51/pl + 1000 plants/Ha x €0'33/pl | €1,350/Ha |
| The cost of **ungrafted** plants are: 3000 plants/Ha x €0.21/pl + 1500 plants/Ha x €0.05 /pl | €705/Ha |
| Difference | €645/Ha |
| Always much lower than the cost of disinfecting with MB, about €6000/ha | |

## CONDITIONS UNDER WHICH GRAFTING IS OF INTEREST

**In melon**

Grafting onto melon (*Cucumis melo*) can be of interest when the pathogen to control is fusarium wilt (FOM), as long as the rootstock is resistant to the strains of the pathogen present in the soil.

Grafting onto hybrids of *Cucurbita (C. maxima x C. moschata*), as long as there is good compatibility between the rootstock and the scion variety, also enables the control, besides fusarium wilt (all strains), of *Phomopsis sclerotioides, Monosporascus cannonballus* ("collapse") and MNSV. In the event of soil infection by nematodes (*Meloidogyne spp*) it is necessary to combine grafting with other techniques (nematicide use, solarization + biofumigation, crop rotation) to reduce their population.

In cucumber

In intensive farming, when the problem is *Phomopsis sclerotioides* or fusarium wilt (*F. oxysporum f.sp.cucumerinum*), grafting onto *Cucúrbita ficifolia* or *C. maxima x C. moschata* allow the disease to be prevented without the need for soil disinfection.

As in melon, if there is a problem with nematodes and the cultivated variety is sensitive, a cultivation practice must be used to reduce contamination, since the rootstocks are also sensitive.

**In watermelon**

Grafting is always of interest. It allows the control of a wide range of pathogens (*F. oxysporum f. sp. niveum, Verticillum dahliae, Monosporascus cannonballus*, MNSV), it affords vigour and productivity to the plants and is much cheaper than disinfection with MB (it was cheaper even when MB costs less than the half the price it does now).

As already indicated in melon and cucumber, the most commonly used rootstock (*C. maxima x C. moschata*) are not resistant to *Meloidogyne*, for this reason, if an important contamination exists, it is advisable to combine grafting with solarization, biofumigation, nematicide application or to use another rootstock type, of the genus *Citrullus,* resistant to nematodes.

**ACKNOWLEDGMENTS**

The author thanks the special collaboration of Mr. Al-Zubi, M.F (Jordan), Mr. Amadio, A. (Italy), Mr. Besri, M. (Morocco), Mrs. Erard, P. and Mr. Fritsch, J. (France) and Mr. Hoyos, P. (Spain), for their valuable help.

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# ALTERNATIVES TO METHYL BROMIDE FOR PRODUCING CUT FLOWERS AND BULBS IN DEVELOPING COUNTRIES

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## ABSTRACT

In 2001 about 9% of the total methyl bromide (MB) was used in developing countries by flower growers for soil fumigation. Demonstration and investment projects undertaken by implementing agencies financed by the Montreal Protocol are promoting the phase out of MB. These trials are leading to commercial adoption of alternatives. Flowers are produced successfully without MB in Colombia where, except for a few trials, MB has never been used. This paper describes progress phasing out MB in floriculture in developing countries. It focuses on those alternatives showing the highest rate of commercial adoption: Steam, compost, production in substrates and some alternative soil fumigants.

**Key words:** Soil pasteurisation, steam, substrates, soilless cultivation, floriculture, alternatives to methyl bromide, compost, integrated pest management, fumigant

## INTRODUCTION

Commercial floriculture has increasingly taken root in developing countries during the last few decades as the climatic conditions are suitable and allow for year round production at reasonable costs. Cut flowers are exported to the developed world where they must meet the demand for high quality and stringent phytosanitary requirements.

Everywhere in the world flower production may be seriously threatened by soil-borne pests and diseases that can lead to very high losses in yield and quality. Among these, root knot nematodes (*Meloidogyne* sp.), and to a lesser extent cyst nematodes (*Heterodera* sp.), can be particularly troublesome (Arbeláez *et al.* 1985; Osorio 1995; Navarro 1995), as well as fungi (*Fusarium, Verticillium)* and some bacteria, particularly crown gall, *Agrobacterium tumefaciens* (UNIDO 2004). Weeds such as nutsedge, *Cyperus* spp (Chaverri and Gadea, 2001) can also cause production problems. Eradicating these noxious organisms from the soil can be difficult and sometimes the only recourse is soil disinfestation. Traditionally, the treatment of choice has methyl bromide (MB) given its wide spectrum of action, its efficacy and its usually low cost.

In developing countries, MB phase out is mainly being achieved through demonstration and investment projects carried out by the implementing agencies of the Montreal Protocol. Consumer preference for agricultural products using fewer pesticides, and increasing environmental awareness, are also pressuring growers into adopting alternative methods to MB to minimise and even avoid soil fumigation.

Although adoption of alternatives faces some hurdles, there are also valuable success stories of cut flower production without MB: Colombia for example, as the second largest world flower exporter after Holland with floriculture exports valued at over US$700 million in 2003, does not use any MB for producing flowers (ASOCOLFLORES 2004). Growers were forced to look for alternatives more than thirty years ago because MB fumigation was phytotoxic to some flowers such as carnation due to bromine fixation and accumulation in soil high in organic matter.

## METHYL BROMIDE USE AND PHASE-OUT IN FLORICULTURE IN DEVELOPING COUNTRIES

Intensive floriculture has been classified among the high MB consuming sectors in the world: Flowers accounted for approximately 9% (1470 tonnes) of MB consumption for soil uses in developing countries in 2001 (MBTOC 2002).

**Projects conducted under the MLF in floriculture**

Twenty-eight projects, fully or partially relating for floriculture, have been approved and undertaken. Of these, 9 were demonstration projects and have been completed and 19 are ongoing; the latter figure is composed by 17 investment projects and 2 projects for information dissemination. Projects cover a wide variety of flower species in all regions where floriculture is important and MB is consumed. Propagation materials (cuttings, plugs, mini-plants) are also considered within some projects as MB is also used for their production. Table 1 below illustrates MB elimination expected from these projects in different parts of the world.

Table 1: Demonstration and investment projects for the flower sector. Geographical distribution and amount of methyl bromide to be phased out

| Region | No. of demonstration projects | No. of investment Projects | No of information projects | MB tonnes to be phased out |
|---|---|---|---|---|
| Latin America | 5 | 8 | | 336.03 |
| Africa | 2 | 5 | | 414.6 |
| Asia/ Middle East | 2 | 3 | | 139.3 |
| CEIT | | 1 | | 3 |
| Global | | | 2 | |
| TOTAL | 9 | 17 | 2 | 892.9 |

Source: MBTOC Assessment 2002; MLF data, 2004.

Demonstration projects aim to evaluate alternatives and adapt them to local conditions. The included holding workshops with stakeholders, and raising awareness about MB issues. An effort was made to transfer technologies from countries that already used alternatives. Trials were established on farms and research stations to evaluate and compare the efficacy, yields and practical viability of alternatives compared to MB. A wide range of alternatives for floriculture were tested in different countries (Table 2).

Table 2: Main alternatives tested in demonstration projects (floriculture) in developing countries

| Alternatives | Countries |
|---|---|
| **1- Non-chemical** | |
| Biofumigation | Guatemala, Turkey |
| Compost, organic amendments | Costa Rica, Kenya |
| Resistant varieties | Syria |
| Soil-less culture | Dom. Republic, Guatemala, Kenya |
| Solarization | México |
| Steam | Argentina, Costa Rica, Dom. Republic Guatemala, Kenya, Syria, Turkey |
| **2- Chemical** | |
| Dazomet | Argentina, Costa Rica, Dominican Republic, Kenya, Mexico, Turkey |
| Metam Sodium | Argentina, Costa Rica, Dom. Republic, Kenya, México |
| 1,3 Dichloropropene | México, Turkey |
| **3- Combination Treatments** | |
| Metam Na + 1,3 D/ Pic | México |
| Biofumigation + solarization | Dominican Republic |

Source: MBTOC Assessment 2002

Investment projects, on the other hand, aim to eliminate MB use by assisting commercial adoption of those alternatives identified as technically and economically feasible for the particular country and crop situation involved, either by demonstration projects carried out previously or from experience derived from similar regions and situations. The main alternatives selected for these projects in different regions are presented in Table 3 below. Investment projects will account for early phase-out of nearly 900 T of MB by 2008.

Table 3: Alternatives selected for investment projects and commercial adoption

| Alternatives | Region |
|---|---|
| Steam | Africa, Asia, Latin America, Middle East |
| Substrates | Middle East, Latin America, Africa |
| Dazomet, 1,3 D, Metam sodium, other chemicals | Middle East, Africa |
| Solarization | Africa, CEIT |

Source: MBTOC Assessment, 2002

Important lessons learnt from these projects are:

- Effective alternatives to MB have been found for all pests and diseases affecting flower production. These work best when used within an Integrated Pest Management (IPM) programme.
- The capability to adapt to local conditions is essential to the success of any alternative.
- Alternatives evaluated can be introduced to developing countries within periods of 2-3 years. In fact, activities related to demonstration projects have encouraged skilled, large-property flower growers to adopt alternatives on their own initiative in several countries e.g. Kenya, Colombia, Costa Rica, Ecuador.

## COMMERCIAL ADOPTION OF ALTERNATIVES TO METHYL BROMIDE IN FLORICULTURE

Substituting MB usually requires growers to adopt new production approaches. Although effective alternatives are available, there is no single replacement for MB. Rather, an integrated programme, involving different measures which together lead to disease reduction, should be put in place. Depending on the pests to be controlled, environmental conditions, supplies, infrastructure available and others, a particular programme might be more suited for a certain situation.

The following alternatives have been shown to give successful results in commercial floriculture in developing countries:

### Steam sterilization (Pasteurization)

Pasteurization or steam sterilization of the soil is a process by which pests, diseases and weeds present in the soil at a given time are killed by heat. In simple terms, this involves injecting or otherwise diffusing hot water vapour into the soil with the aid of a boiler and conductors. As a general rule, it is recommended that the coldest spot in the soil or substrate is held at 90°C for ½ hr. If carried out properly, steam is probably the best alternative to MB, proving equally effective.

Many variables influence the success and cost effectiveness of steam. For example, the boiler and diffusers used, soil type and structure and soil preparation (Morey 2001; Pizano 2001). The depth or volume of soil or substrate to be treated directly influences costs of this alternative. Thus, steam can be made economically feasible when disease incidence is maintained at a low level when it is part of an integrated management system. Very careful growers can even perform strip treatment (growing beds only) saving 40% of the costs (Carulla 2004). Some problems may arise in association with steaming itself, such as accumulation of soluble salts (particularly manganese), ammonium toxicity and recontamination.

Just like fumigants, steam is a biocide, killing all living organisms within the soil. To correct this problem, compost and/or beneficial organisms such as *Trichoderma* and beneficial bacterial cultures should be added immediately after steaming (Carulla 2002; Jaramillo 2004).

Steam has other benefits when compared to fumigants, as these usually require a waiting period – sometimes at least thirty days - before replanting can occur, while steamed soils can be replanted immediately. This sole fact adds one whole month of flower production to steamed areas, representing for example about 135,000 exportable carnation flowers per hectare (Carulla 2001).

**Compost**

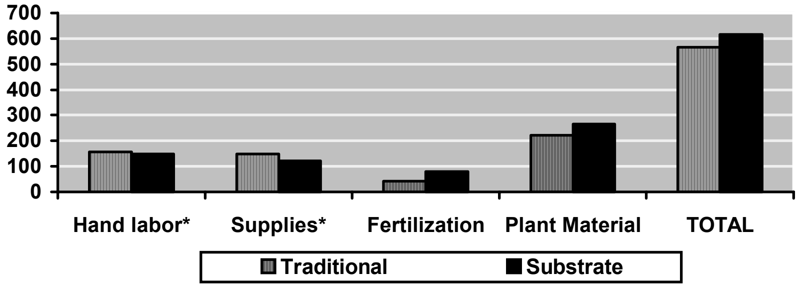
Compost is not only an excellent fertiliser but also contains high amounts of beneficial organisms that prevent and help control soil-borne diseases. Further, it contributes to restoring natural soil flora and increases water retention capacity. Compost enriched with beneficial organisms such as *Trichoderma* provides very good control of soil fungi such as *Phoma* and *Pythium,* in *Dendranthema* and *Alstroemeria* ranges (Valcárcel 2001; Jaramillo 2004). Growers incorporating compost to the soil and following a strict IPM programme have been able to produce highly profitable yields without any kind of soil sterilisation being necessary (Jaramillo 2004).

For the reasons above, and because it also takes care of large amounts of plant refuse generated in flower farms, growers in many countries now produce compost, e.g., Kenya, Brazil, Costa Rica, Colombia, Ecuador and Zimbabwe.

**Soilless substrates**

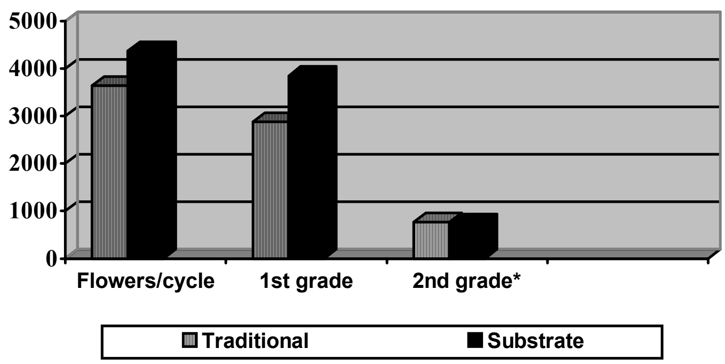
Production of cut flowers and propagation materials in substrates is rapidly expanding in developing countries, especially since growers started to find and successfully adapt locally available, cheap substrates such as rice hulls, coir, sand and composted bark (Calderón 2001). An estimated 40% of all carnations produced in Colombia (around 500 Ha) are presently produced in substrates. Although setting up a soilless production system is expensive – around 47% more expensive than traditional ground beds - growers are able to compensate the extra cost through significantly better yields (20-25%) that result from higher planting density, optimum plant nutrition and better pest and disease control (Figure 1) (Carulla 2001; Valderrama & La Rota 2001; Cavelier 2003).

Figure 1: Carnation production costs: Traditional vs. Substrate (rice hulls). 2- year cycle (USD/ha). *Includes herbicide application and fumigation with Telone C-17 (Source: La Gaitana Flowers, 2004).




Production costs are about 8% higher when grown in substrates compared to traditional production in ground beds where the soil is fumigated with Telone C-17. However, when yields and quality are considered (Fig.ure 2), it is clear that more and better quality flowers are harvested, and the higher investment pays off.

Figure 3. Carnation yield and quality: Traditional vs. Substrate (rice hulls) (USD/ha). Two year cycle. *Includes non/exportable flowers (Source: La Gaitana Flowers, 2004)



A simpler example relating to rose production in substrates is presented below. Whilst investment for substrate production is substantially higher, so are yields and quality of flowers obtained. Even though the production cycle is shortened this is not considered a drawback by growers since the market is constantly requiring new varieties.

Table 4. Comparison of traditional rose production in ground beds with production in rice-hull substrate

| | **Ground beds** | **Substrate** |
|---|---|---|
| Plant density | 60,000 plants/ Ha | 86,000 plants/ Ha |
| Setup cost/ 30 $m^2$ bed | U$57 | U$ 80 |
| Yield | 1.2 million flowers/ year | 1.5 million flowers/ year |
| Production cycle | 5 – 8 years | 3 years |

Source: Flores Sagaró

Commercial production in substrates in increasing in most Latin American countries where commercial floriculture is important, e.g. Brazil, Ecuador and Colombia (Pizano 2002cd). It is also becoming apparent in Africa, e.g., Kenya and Uganda (Pizano 2001; UNIDO 2003, 2004; MBTOC 2002). It does, however, pose new challenges associated with water and nutrition management, pest and disease control and the environment, since to avoid soil and ground water contamination the nutrient solution should be re-circulated.

**Fumigants**

Trials and experiences with soil fumigants in floriculture have shown that their effectiveness varies with factors like the pathogens to be controlled, soil characteristics and crop species. These chemicals have been combined together or with other options such as steam with variable results (Arbeláez 2000). Several fumigants are being evaluated as alternatives to MB, both by commercial growers in many countries, as well as in several demonstration projects conducted by the Montreal Protocol's implementing agencies (Pizano 2001). The most promising results have been obtained with metam sodium, dazomet and 1,3-dichloropropene + chloropicrin (Correa 2001; Navarro 1995; Cavelier 2003).

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# METHAM SODIUM AS AN ALTERNATIVE TO METHYL BROMIDE FOR CUT-FLOWER PRODUCTION IN EUROPE AND AFRICA

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## ABSTRACT

Metham sodium (MS) is a multi-purpose, MITC-generating soil fumigant that is used in many countries to control soil diseases, nematodes, weeds and agro-bacteria in a range of crops including cut-flowers, tomatoes, peppers, cucumbers, aubergines, melons, lettuces, carrots and strawberries. The most effective method for applying MS is to use rotary spading injector (RSI) equipment. RSI is a closed system that mixes the fumigant throughout the soil layers using rotating spading blades. It distributes more MITC in the topsoil (upper 20 cm) than the subsoil which avoids drinking water contamination. The paper describes methods to optimize the application of MS.

## INTRODUCTION

Metham sodium (MS) is a multi-purpose, MITC-generating soil fumigant that is used in The Netherlands and other countries for controlling soil diseases, nematodes, weeds and agro-bacteria in a range of crops including tomato, pepper, cucumber, aubergine, melon, lettuce and carrot, strawberry and cut-flowers. Beneficial side effects are the destruction of weeds and the growth stimulation of the crops. It is safe to the user and the environment and does not leave any residues.

MS has been used for over 10 years in countries such as The Netherlands, Belgium, France and Germany and also in several countries in South and Northern Africa. In Europe, several thousand of hectares are treated each year with MS. MS is known to remain in the topsoil and to not pollute groundwater. The fumigant is distributed evenly throughout the soil giving effective nematode and weed control. Plastic sheeting after application improves the performance of MS.

For the past decades much research has been conducted to ensure environmental requirements are met for limiting the emission of active compounds and the degradation of the the air, deep ground water, deeper soil layers and the exposure of applicators.

It was necessary to develop an application method that prevented distribution of the MITC to the subsoil or surface water. This research resulted in the development of the rotary spading injector (RSI), a closed system that mixes the fumigant throughout the soil layers using rotating spading blades, to control nematodes in particular. The distribution of MITC is higher in the topsoil (upper 20 cm) and lower in the subsoil (90 cm) which avoids potential contamination of drinking water. This paper describes the key features of fumigation with MS.

## TECHNIQUES

MS is sold as a water-soluble liquid. It can be applied by RSI, drip irrigation, sprinkler and flood water applications, injection by blades or shanks, and watering can.

Generally, the soil before should be thoroughly cultivated prior to MS application in order to break up clods and to loosen the soil. It is advisable to know the soil type, temperature, structure, organic matter content, and mineral makeup as these factors can directly affect its mobility and pesticidal performance. For all applications in the field it is necessary to monitor the wind conditions, air and soil temperature.

For best results, the soil temperature should be greater 10 °C within 15 cm of the soil surface; the soil moisture should be 50 to 80%; and the soil should be free of crops and residues. MS should be applied as close as possible to the problem area and it has to be well distributed. To achieve the best performance it may be necessary to adapt equipment to the local conditions.

Downwind odour should be avoided whenever possible. It is important to observe best management practices to minimise off-site movement of odours when applying MS, and to consult local agricultural regulations for requirements.

After the soil has been treated, it must be left for 2-4 weeks, depending on the temperature and moisture of the soil, and the type of soil. Decomposition of any product still remaining in the soil after that time can be accelerated by aeration. The waiting time is necessary to let the MS and MITC penetrate into the required depth of the soil.

**ROTARY SPADING INJECTOR**

Of all the possible techniques that can be practiced to apply MS to the soil, RSI is the technique that gives the best results. The RSI has the advantage over other methods of distributing the best MS concentrations over the whole width and depth of the working area, in contrast to all the other application methods that only treat one layer of the soil.

The RSI is a closed system and is therefore the safest method. Trials with the rotary spading injector have proven that:

- The MS stays in the tillage layer and does not penetrate into deeper soil, this is in accordance with the drinking water requirements.
- The MS is better distributed into the top 20 cm.
- The machine successfully distributes the fumigant evenly through the total depth of the tillage layer including cultivators.

The RSI is equipped with the following parts:

- A <u>tractor</u> to pull the RSI, there is a suitable tractor available for each application.
- A <u>goosefeet rotary spader</u> to mix the fumigant into the soil.
- A <u>driven smooth roller</u> to seal the surface.
- <u>Coulter discs</u> to cut organic material and prevent dragging.
- A <u>front or rear injection unit</u> with wide angle nozzles for perfect spraying.
- An <u>accurate ground driven pump</u> to pump the fumigant for spraying.
- A <u>power harrow</u> for crumbling the soil.
- A <u>storage tank</u> for MS.

The base for the RSI machine is a 3 meter wide rotating spading machine that is equipped with four 70 cm wide goose-foot shares to apply the fumigant and a power driven harrow and power driven roller.

The fumigant is applied at the required depth and is mixed throughout the tillage layer by the rotating spading blades. Afterwards the soil surface is leveled and compacted by the rotating harrow and sealed by a power driven roller. The driving speed should be adapted to the required quality or result. The time for treatment of a piece of land can be calculated by means of: the total surface in m³, speed of the machine in m/hr and the width of the machine in meters.

For a good performance, the driving speed of the RSI should not exceed 3.5 km/h although the MS is fully adapted to the machine speed (not for spading only). The RSI works efficiently as it operates on a reduced MS dose and is capable of covering large areas in a relatively short time. The soil is homogenized with the RSI and the surface sealed with a roller, the spading depth is 35 cm.

When MS is injected soil it should be sealed with a roller. Sandy soils should be sealed with plastic sheets for two days after treatment to retain the gas in the soil during the treatment period. MS should be applied at the rate of 300 and 1200l/hectare. It should be injected at a dept of 15 cm. The treated area should be covered by gas-proof plastic sheets, with sufficient sheet over the edges to be buried at least 15 cm below the general soil surface.

The optimum temperature for treatment is 12-32 °C. At low temperatures MS moves slowly in and from soils. Movement is particularly slow on wet soils.

At optimum temperatures, the soil may be used for planting or sowing 3 weeks after treatment. Before planting or sowing it is good to open the soil surface in order to break down the MITC as soon as possible. It is also wise to carry out a cress-test before planting or sowing to check for fumigant residues.

# A SYSTEMS APPROACH TO REPLACE METHYL BROMIDE SOIL FUMIGATION

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## ABSTRACT

Over a decade ago, the crisis of a MB phase-out in U.S. agriculture began. At the time, the means by which to replace the broad spectrum activity and other favorable attributes of MB were not clearly understood. Probably the most significant outcome has been the systems type approach taken to reconstruct a new integrated pest management strategy. Clearly it has not been a simple substitution process, but rather a process of coupling and integration, following by an examination of interaction. This paper provides highlights and a basic overview of Florida research efforts to identify and evaluate various chemical and nonchemical alternatives to MB for the management of soilborne pest and diseases in south Florida fruit and vegetable crops. Field research efforts have co-applied different fumigants, herbicides, and other alternatives to achieve pest control efficacy and crop yield response similar to that achieved with MB. The research focused on causes of treatment response inconsistency. For example, this research has repeatedly demonstrated that the pest control efficacy of the available fumigant alternatives is generally more highly dependent upon uniform delivery and spatial distribution within the field. To address problems of application uniformity and treatment performance inconsistency, significant refinements have been made in soil application technologies of the alternative fumigants via standard shank, mechanical incorporation, and with new, more gas impermeable plastic mulch technologies to reduce overall field application rates and soil emissions. Other significant refinements include 1) The integration of new tillage operations; 2) New irrigation application practices to enhance the performance of chemigated fumigant alternatives; 3) New pest monitoring practices; and 4) Tthe recognition of the importance of weeds as reservoir hosts for nematodes and other disease causing agents.

## SOIL COMPACTION AS CAUSE FOR INCONSISTENCY

In addition to the development of new chemical application systems, significant improvements have also been made in our understanding of the gas phase movement of fumigants in soil. In an attempt to determine the cause of poor crop performance and pest control consistency after soil fumigation with methyl bromide (MB) or 1,3- dichloropropene (1,3-D;TeloneII), field surveys were conducted of nematode problem fields. In each of the problematic fields surveyed, a compacted zone (traffic layer) occurred between a soil depth of 2 to 8 cm below the soil level of the row middle, extending to a soil depth of 38 to 45 cm.

In practical terms, the compaction zone appears to occur just below the depth of the deepest tillage operation used within the field. It was felt that the presence of the compacted zone inhibited downward diffusion and overall success of fumigant treatment, and by so doing, simply delayed the time and degree to which various soilborne pests and pathogens upwardly recolonize the plant root system.

Subsequently, field experiments were conducted during the summer and fall of 2003 to determine the potential impact of the soil compacted zone on fumigant movement of MB and 1,3-D in soil (Noling *et al.* 2003). In these studies, chisel plows were used to destroy the compacted zone (traffic layer) to a depth of 40 cm in alternating strips throughout the field. Gas concentrations of 1,3-D (trichloroethylene) were then periodically monitored after fumigant soil injection in areas with and without chisel plowing. Fumigant treatments included broadcast and in-row applications of MB and Telone II. A Gastek® Model GV-100 gas sampling vacuum pump together with Gastek detector tubes (No.132HA) specific to trichloroethylene (0-500 ppm) were then used to characterize fumigant concentrations at two soil depths (20, 45 cm) at two time intervals after soil fumigation in each tillage treatment.

For these studies, chisel plowing was qualitatively observed to significantly reduce soil penetration resistance using a simple probe tipped metal rod to characterize changes in soil bulk density. Based on analysis and comparison of gas concentrations at the two soil depths, it would appear that the downward diffusion of Telone II is significantly restricted by the presence of the soil compacted layer. In plots chisel plowed to a depth of 40 cm and the compacted layer destroyed prior to soil fumigation, fumigant concentrations were consistently higher at the 45 cm soil sampling depth compared to the shallower 20 cm soil sampling depth for both in-row and broadcast treatments. Higher soil concentrations of trichloroethylene were observed with in-row applications at both soil depths compared to broadcast treatments. For the broadcast treatment, the compacted zone appeared to completely restrict 1,3-D downward diffusion to the 45 cm soil sample depth at one of the experimental sites.

In summary, these experimental results suggested that unless destroyed by deep chisel plowing prior to soil injection, the presence of a soil compaction layer restricts downward diffusion in soil of 1,3-D. It is assumed that these new tillage/application methods will not only reduce potential emissions of 1,3-D from treated fields but also significantly improve overall crop response and nematode control, particularly in the deeper, sandy soils of central Florida.

## POSSIBLE CAUSES FOR INCONSISTENCY WITH CHEMIGATION

Most Florida vegetable soils are classified as fine sands with low water holding capacity and high hydraulic conductivity, which allows water to easily and, in some cases the chemical in them, rapidly percolate through soil.

In an attempt to address the causes for inconsistency with various chemigated fumigants, studies were conducted during the period 2000-2002 to evaluate the spatial distribution of drip irrigation water colored with a blue dye when applied through one or two drip tubes at various irrigation injection times, schedules, and total water volumes (Eger *et al.* 2001; Noling *et al.* 2001). Distribution of drip irrigation water for irrigation run times of 1 to 12 hours was evaluated using a water soluble blue marking dye (Signal®). One and two drip tubes per bed were evaluated in all trials. Width, depth, and area of soil covered by the drip water were evaluated by digging cross sections across the beds to the depth of the wetting front. Mapped grid coordinates were then field recorded and later entered into the computer to analyze depth, width, and size of treated or dye stained areas relative to bed size, irrigation run time, water volume, drip tube number, and other treatment regimes.

For these studies, the relation between average depth, width, and cross sectional bed area wetted by drip irrigation water was determined to increase as a direct allometric function of total water volume applied, and the functional relationship was remarkably similar for all experimental sites. For the irrigation run times and total water volumes evaluated in these studies, there was little indication that one drip tube manufacturer was any different from another when equal volumes of irrigation water were compared.

In these studies, it was virtually impossible to wet more than 50-60% of the raised bed with a single drip tube per bed. For a given water volume, the use of two tapes per bed always increased spatial distribution of irrigation water simply because of the spacing between drip tubes and the increased number of emission points along the bed. In the sandy soils of Florida and discounting fuming action, two drip tubes will be required to treat upwards of 85-95% of the entire mulch covered bed with any chemigational alternative to MB. There are, however, significant economic, horticultural, and regulatory impediments to overcome to broadly implement a chemigation strategy relying on two drip tubes per bed.

In the overall analysis of the relationship between total irrigation water volume and spatial distribution of the wetted zone, it appears that most bed wetting occurs in the time to deliver the first 1100 liters of water expressed per 30 linear meters of row. If a maximum depth of 40-50 cm from the top of the bed is assumed, then irrigation run times required to deliver water volumes of 375 to 750 liters per 30 linear meters of row should not be exceeded so as to retain the wetting front within the future rooting zone of the plant. It would also appear that irrigation injection schedules previously utilized to field test the drip applied fumigants in Florida field research have significantly underestimated water volume requirements for maximizing bed coverage (and quite possibly, pest control efficacy?).

**FIELD MONITORING FOR ROOT-KNOT NEMATODE**

With MB soil fumigation, specific grower decisions regarding soilborne pest and disease monitoring or management were never truly essential because of the broad spectrum efficacy of the fumigant. In the post MB era of Florida crop production, new pest monitoring systems will likely be needed to determine whether nematodes such as root-knot nematode are the cause for poor crop performance or to determine the need for nematode management.

To initiate the development of a new monitoring system, eight commercial vegetable fields were comprehensively surveyed to explore the use of root gall assessment, rather than soil sampling, to characterize root-knot nematode (*Meloidogyne* spp.) spatial distribution and mean gall severity (Noling *et al.* 2003). Spatial distribution was characterized by systematically removing plants at increments of 15 m along rows, sequentially across the field after final crop harvest. Basic sampling units consisted of 6 row blocks, each row 198 m long. Field sizes ranged from 2 to 4 acres. Mean galling was estimated for a range of sample sizes and targeted field locations for each of 96 blocks.

Spatial analysis of patterns of field distribution of root-knot nematode indicated a nonrandom, aggregated pattern in most of the fields surveyed. These same analyses also suggested that the crowned areas of the field or field centre is often the site which recolonize first with root-knot nematode after soil fumigation. This early recolonization by root-knot nematode may occur because these crowned areas are possibly the hottest and driest areas of field at the time of soil fumigation, and the more rapid escape of the fumigant may afford nematodes greater survival. At other experimental sites, root-knot nematode recolonization appears to occur within rows rather than between rows. Interestingly, sampling precision was generally less variable and often required fewer samples when plants were randomly obtained exclusively from the crowned areas or field middles rather than from plants acquired randomly from throughout the entire field.

Analysis of these data also indicate that as overall root gall severity increases in the field, the number of plants which must be uprooted and examined for root galling for a given level of sampling precision decreases. For a given sample size, sampling precision increased significantly when overall root gall severity was greater than 5 (scale 0-10) in any given field. This was fortunate because the visual acuity of growers to detect the presence of galling on roots also appears to be at or near a root gall severity index of 5. At this overall level of root galling, growers must inspect a minimum of 4 to 6 plants per 6-row field block to achieve acceptable precision. When the nematode problem in the field is less severe and overall root gall severity less than 5, as many as 2 to10 more plants must be inspected to accurately assess nematode problems within the field with the same level of sampling precision.

Rather than soil sampling, the results of these studies suggests that use of root galling indices of crop plants acquired systematically from grower fields after final harvest of the crop can be used as excellent bioindicators to accurately characterize root-knot nematode infestation level and for revealing patterns of field distribution.

**THE IMPORTANCE AND INTERACTION OF WEEDS**

Loss of weed control associated with alternatives to MB constitutes a major threat to nematode management in the future. In our efforts to define alternatives to MB, we have observed how ineffective some pest management tactics can be for weed control, while other studies have documented the importance of weeds to serve as excellent hosts to nematodes (notably *Meloidogyne* spp.) as well as various soilborne disease pathogens.

Our working hypothesis has been that weed density, species diversity, and the number of problematic fields will increase as we come to rely on less effective broad spectrum control measures, the consistency of which is further reduced by climate and grower application error. Anticipating a future increase in weed pressure and problems, a joint research programme was initiated to characterize the role weeds can play by serving as alternative hosts to nematodes and other disease pathogens.

During 2002, comprehensive field surveys of seven commercial vegetable fields were conducted in east, southwest, and west-central Florida to evaluate the host status of various weeds to root-knot nematode (*Meloidogyne* spp.) (Noling *et al.* 2002). Weed roots were collected from each field and returned to the laboratory where the weeds were identified and indexed for root gall severity and, via a staining process with Phyloxine B, relative densities of egg masses per gramme of weed root. Simultaneous to the root staining operation, a subsample of appropriate weed roots were preserved for root-knot nematode species identification.

A series of grower field demonstration experiments, consisting of treatments which manipulate weed densities into broad categories between high and low, was also conducted to demonstrate the importance and direct linkage of weed density and management to nematode population suppression. For these experiments, six treatments were evaluated in commercial tomato or pepper fields. Three of the treatments included mulch covered rows which were either 1) In-row fumigated with MB chloropicrin 67/33 (350 lb/a, ≈ 392kg/ha); 2) Telone C35 (26 gal/a; ≈ 243 l/ha); or 3) Received no fumigant treatment. The remaining treatments represent the impact of different cultural practices on weed growth in the row middles. The cultural practices or treatments included 4) Row middles receiving pretransplant soil applications of glyphosate; 5) Middles which were twice rotovated for early season weed control; and 6) Middles in which a tightly woven, polypropylene nursery ground cloth fabric was installed to totally exclude weed growth in the row middles. All treatments were initiated at the beginning of the cropping season and nematode samples collected at the end of the growing season after final pepper harvest.

In five of the seven fields surveyed, *Meloidogyne incognita* was the exclusive root-knot nematode species recovered from weed roots. A new root-knot nematode species, *Meloidogyne mayagensis*, was recovered from one of the seven field sites. In one field location, a mixed population of *M. incognita* and *M. javanica* was recovered from weed root samples. Fifteen weeds commonly found in the sandy soils of south Florida were evaluated for host suitability to root-knot nematode. In general, nematode galling and egg production was observed on the roots of all fifteen weed species from at least one of the seven field survey sites.

With some weed species such as ragweed, cudweed or goosegrass, root-knot nematode galling and egg production was variable between survey site locations and was not correlated with differences in nematode species. Six of the fifteen weeds species supported only low to intermediate levels of root-knot nematode reproduction at most sites. These included common ragweed, goosegrass, crabgrass, cudweed, and yellow nutsedge. Yellow nutsedge was not recovered from the nematode infested areas of all field survey sites. Nematode galling and egg production was highest and most efficient on various pigweed and nightshade species, common purslane, clover, Sesbania, sand vetch, and Carolina geranium. Although weed densities were not quantified at each field survey site, weed densities were typically very high, and in most cases, provided complete ground cover in areas between raised beds, the row middles.

As expected, MB significantly reduced but did not eradicate soil population density of root-knot nematode, and soil populations were near equivalent to those in the row middles receiving pre-transplant glyphosate treatment. At seasons end, weed growth in the glyphosate treated middles consisted of a near complete ground cover of various grasses, the most important of which was goosegrass and crabgrass. Root-knot soil populations built to their highest levels on peppers in the non-fumigated mulched covered beds and on weeds in the rotovated middles. Weed densities were highest and most diverse in the rotovated middles, consisting of a complete 100% ground cover of various grasses and broadleaf weed species. No nematodes were recovered from soil below the ground cloth where no weeds were permitted to grow.

In summary, this research has demonstrated 1) The weed host range of root-knot nematode is extremely broad; 2) Nematodes cannot be effectively managed <u>unless</u> weeds are also effectively and simultaneously managed in the field. Weeds which are allowed to grow and increase in numbers, particularly in-between mulch covered rows, serve to increase soil population densities of nematodes and perpetuate the nematode and, quite possibly, disease problems from one cropping season to the next; and 3) Unmanaged weed growth can have a very destabilizing effect on pest populations and crop loss.

Given the extent to which nematode population density increased in the presence of weeds in the row -middles, we would ask growers to consider the consequence and potential impact of such an effect. In the ground cloth experiments, nematode densities were nearly twice as high in the middles than in the fumigated, plastic mulch-covered plant rows. Irrespective of what kind of pest control is achieved in the fumigated bed, when the season is over and mulch removed, the soil from all areas will be mixed by disking operations which follow. It is not inconceivable to easily produce doubling or even tripling effects to overall nematode and disease population levels when weeds are allowed to grow and increase pest population levels in the row middles. One might even conclude that much of the need for soil fumigation may be predicated on the impact weeds have on increasing and preserving soilborne pest populations at high levels at seasons end. Put another way, mandate the continued need for broad spectrum soil fumigants for nematode control. These results demonstrate the continuing need for truly integrating IPM practices, including the development of a catalogue and weed management matrix which ranks the importance of specific weeds, and their control, for nematode management.

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# NEW EQUIPMENT AND IMPROVED FORMULATIONS OF 1,3-DICHLOROPROPENE AND CHLOROPICRIN

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## ABSTRACT

The phaseout of methyl bromide, as prescribed by the control measures of the Montreal Protocol, has stimulated public and private research that has advanced the technology of preplant soil fumigation and identified technically and economically feasible alternatives to methyl bromide globally. New formulations, application methods and equipment involving the fumigant 1,3-dichloropropene with or without chloropicrin have been developed that provide growers with highly effective options for the application of fumigants. Drip irrigation tubes provide higher efficacy, lower costs and reduced worker exposure relative to shank injection techniques. The Yetter Coulter pre-bed, in-row shank injection equipment places the fumigant deep into the soil which results in better coverage of the fumigant throughout the root zone, and seals the soil at the same time. These and other developments offer advantages to growers in terms of higher efficacy, lower costs and reduced exposure of workers to fumigants during application.

**Keywords:** 1,3-dichloropropene, chloropicrin, drip application, shank injection, efficacy, formulations, economics, Yetter Coulter

## INTRODUCTION

Control measures in the Montreal Protocol require that developed countries cease all production and import of methyl bromide (MB) by 1 January 2005, except for amounts exempted for Quarantine and Pre-Shipment (QPS) and Critical Use Exemptions (CUE). These measures have stimulated much research internationally to identify technically and economically feasible alternatives and to demonstrate their value. It has also served as a catalyst to develop new formulations, application techniques and equipment which provide growers with new tools and options for crop production. It is likely that some of these new options would not have been developed as rapidly, or at all, without the stimulus of the MB phase out schedule.

Modern economic, regulatory and environmental concerns are making it increasingly difficult to develop and register new soil fumigants to replace MB. Fumigants, almost by definition, are anachronisms compared to modern trends in crop protection. They are broad-spectrum products with use rates of many kilograms per hectare compared with use rates of just a few milligrams per hectare that are now commonplace for other classes of crop protection chemicals. In addition, a relatively small global market for preplant fumigants makes it a low priority target for investment by pesticide manufacturers.

Since it is unlikely that new fumigants will be registered, it makes good sense to optimize those already available. New formulations, application methods and equipment are ways to improve the value of existing fumigants and provide more options for growers as they phase out MB. Dow AgroSciences has been active in each of these research areas and each one of these is discussed in turn in this paper. Dow AgroSciences has worked cooperatively with numerous researchers to bring new technology to the marketplace. In many cases, this new technology results in increased application flexibility, improved yields, lower costs and reduced exposure for applicators.

## NEW FORMULATION TECHNOLOGY

The earliest application of preplant fumigants often utilized heavy equipment that dragged shanks behind a tractor and injected the fumigant 50 cm or more below the soil surface. This application method is effective and is still a common practice in many countries. However, factors such as water conservation, economics, worker exposure, soil emissions, changes in agronomic practices and application logistics have stimulated demand for new application methodology for fumigants. This demand has been met by the widespread use of drip tubes for irrigation. Fertilization has also provided another alternative for application of some fumigants. Most fumigants either did not lend themselves to this technology or needed formulation changes to ensure they remained uniformly distributed in irrigation water during application.

Dow AgroSciences developed two formulations specifically for application through drip irrigation tubes. These new formulations contain emulsifiers and include either 1,3-dichloropropene (1,3-D) alone or a combination of 1,3-D and chloropicrin. The emulsifiers allow the fumigants to be metered directly into irrigation water and ensure the fumigants remain dispersed uniformly in the irrigation water as it flows through the drip tubes and percolates into the soil. Table 1 lists the components of Dow AgroSciences soil fumigants that can be applied by shank injection or drip irrigation.

Table 1: Components of soil fumigants that allow shank or drip irrigation

| Product(s) | 1,3-D Gm/L | 1,3-D (%) | Chloropicrin Gm/L | Chloropicrin (%) | Total Gm/L | Shank (S) or drip irrigation (D) |
|---|---|---|---|---|---|---|
| Telone*<br>Dorlone* | 1178 | 97.5 | - | - | 1210 | S |
| Telone* EC<br>Condor* | 1162 | 93.6 | - | - | 1210 | D |
| Telone* C-35<br>Telopic*<br>Doublestopper* | 825 | 61.1 | 465 | 34.7 | 1342 | S |
| InLine*<br>Telopic* EC | 808 | 60.8 | 442 | 33.3 | 1342 | D |

* Trademark of Dow AgroSciences LLC

## NEW APPLICATION TECHNOLOGY

Application of fumigants via shank injection is an effective (Lopez-Aranda *et al.* 2002) application practice for many preplant soil fumigants. However, utilization of drip irrigation tubes to apply fumigants provides some unique advantages. These advantages are summarized in Table 2 and can be categorized generally into higher efficacy, lower costs and reduced worker exposure relative to shank injection techniques. The latter category, reduced worker exposure, is the result of the requirement for very few people to monitor the application and better retention of the fumigant in the soil.

Table 2: Advantages of drip irrigation application of fumigants over shank injection

- Lower use rates
- Better distribution of fumigant in the soil
- Better retention of fumigant in the soil
- Higher efficacy in most soil types
- Lower cost of fumigant
- Better consistency of performance
- Reduced exposure of workers to fumigant
- Utilizes existing drip tubes

From an economic perspective, drip applications have performed well compared to standard applications of MB (Norton 2002, 2003). This is a result of several factors including better distribution of fumigant throughout the root zone (Ajwa *et al*. 2001) and better retention of the fumigant within the soil.

## NEW APPLICATION EQUIPMENT AND TECHNIQUES

There has been a significant amount of research conducted globally to develop and test new application equipment for soil fumigation. Important examples of this research have been conducted in Southeastern USA using equipment known as the Yetter Coulter (pre-bed, in-row application equipment). This equipment utilizes a large disc shaped coulter (76 cm diameter) which opens a narrow slit in the soil for application of the fumigant. The fumigant is applied below the soil surface via a tube attached to the trailing edge of a shank that follows immediately behind the coulter.

The most significant advantage of this equipment is the soil sealing technique that helps retain the fumigant in the soil. A major pathway for fumigant escape is straight back up the slit formed when the coulter and shank are pulled through the soil. Gas will escape through this ‘chimney’ unless the soil is sealed carefully. The Yetter Coulter breaks up this chimney by adding a horizontal plate or ‘beaver tail’ just above the fumigant injection point at the tip of the shank. The seal is completed by a press wheel on the soil surface. The other advantage is that the fumigant can be placed deeper than many other shank application tools which results in better coverage of the fumigant throughout the root zone.

The value and flexibility of this equipment has been proven in a number of research and demonstration trials in the Southeast USA on commercial pepper and tomato crops (Chellemi *et al.* 2001, Busacca *et al*. 2004). The Yetter Coulter equipment can be used for broadcast applications or for ‘in-bed’ applications in the raised bed, plastic-mulch agronomic systems common in this area. In both situations, applications of Telone C-35 (65% 1,3-D plus 31% chloropicrin) resulted in yields at least equivalent to standard MB/chloropicrin (67/33) treatments. To date, this application equipment has been most useful in the lighter soils common in the Southeast USA. In addition to vegetable crops, the Yetter Coulter has also been utilized effectively for fumigations on commercial turf farms.

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# IMPROVED TECHNIQUES FOR THE APPLICATION OF METAM SODIUM

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## ABSTRACT

Among the alternatives to methyl bromide, metam sodium (MS) as a registered product has proven to be an effective solution in the various crop situations. MS is in the third list of revision of active ingredients set up by the EC Directive 91/414 and is fully supported by Taminco. A good disinfection with MS requires the use of the correct application technique: Mixing-injection or drip-fumigation. Soil preparation and surface sealing are also essential for achieving efficacy against soil-borne pests and disease. Field studies and reports from regions with experience in the use of MS for soil disinfestation have shown improved prospects for the recovery of profitability in the production of crops such as strawberry and tomatoes.

**Keywords:** Metam sodium, methyl isothiocyanate, MITC, mixing injection, spade injector, drip-fumigation, profitability, Nemasol, soil fungi, nematodes, soil fumigation, strawberry.

## INTRODUCTION

Metam sodium (MS) is a well known soil fumigant with several decades of world wide use in intensive indoor and outdoor cropping systems. The methods of application and the rates of use have been adapted locally to the crop and the growing conditions along with the field experience, and they were rarely transferable to other growing systems without a good understanding of the behaviour of the product in the soil. Among the various application techniques in use today, two of them are specifically adapted and recommended for MS: The direct mixing-injection, used for the control of nematodes in Potato in The Netherlands for example, and the drip-fumigation used for the control of soil diseases in greenhouse producing vegetables in Spain.

MS is not active as such and it must enter in contact with the soil to generate its active ingredient methylisothiocyanate (MITC). MITC exhibits a strong biocidal effect on nematodes, fungi, weeds as well as on ‘conservation stages’ such as cysts, seeds and sclerotia. In laboratory conditions (Fritsch 1998) the biocidal efficacy of MITC was shown to be twenty times more powerful than that of methyl bromide (MB). The values of the factor concentration-time (CT) obtained for MITC and MB were 202 g.h/m³ and 4,000 g.h/m³ respectively. This shows MS generates one of the most powerful biocidal ingredients made available to the farmers.

In the field conditions, MS and MITC do not move easily in the soil. They are not real gases and their diffusion is limited which may in certain cases decrease the efficacy. The lateral movement of the fumigant on each side of the point of application being limited to 7-10 cm, the technique of application has to compensate for this by placing the product as close as possible to the target and by allowing it to stay enough longer in contact with the pest. In this way, good soil preparation and distribution of MS in the soil are essential.

## APPLICATION BY MIXING-INJECTION

Mixing-injection stands for “injection followed by immediate mixing with the soil”. This technology was developed in The Netherlands (Roosjen 1989) for improving the effectiveness of MS at reduced rates for controlling nematodes on potatoes and flower bulbs.

The success of this technology consists in injecting a layer of MS at 10-15 cm depth and to homogenise it immediately on 25-30 cm depth with a rotating spade (Figure 1). The injection is done by means of spray-fan nozzles mounted behind a “goose feet”; the “goose feet” penetrates the soil down to 15 cm and lifts it gently in order to allow the nozzles to spray the product. The product is distributed evenly in depth and width, increasing in this way the probability that MS or its active ingredient enters into contact with the organism to be controlled.

Rotating spade permits an excellent distribution of the product while avoiding formation of a tillage pan. This equipment is now available in different sizes from various producers. Machines of 1.40 m in width are adapted to the disinfection of greenhouse while 3.00 m models fit the conditions of open field.

The tank containing Nemasol (metam sodium 510 g/l) is inserted in front of the tractor, or at the rear directly onto the spading machine (Figure 2). Pump, Teflon® pipes, pressure control and electronic device provide for a fine control of the quantity of product applied. Large models allow treatments up to 10-15 ha/day.

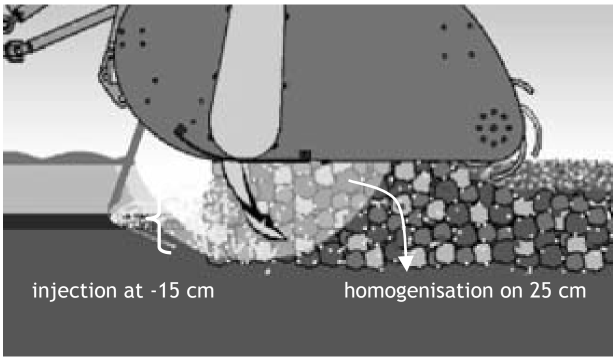


Figure 1

Figure 2

**DRIP-FUMIGATION**

Drip fumigation is suitable for the application of MS since the product is soluble in water. Drip fumigation consists of applying MS diluted in water through the drip irrigation lines at constant dilution (Gerstl *et al.* 1977). Drip fumigation is a suitable for applying MS since it enables the product to be placed close to the pest by entering into contact with every soil particle. Drip fumigation saves water while considerably reducing worker exposure and the environment to the chemical. It can be successfully implemented on a commercial scale (Rabasse 2002).

**Application through the drip-irrigation line**

MS is injected in the drip irrigation lines by mean of a dosing pump in order to achieve a dilution of 1% to 5% (Figure 3). It takes 1 to 4 hours to apply 10 to 40 mm of dilution (Figure 4). The quantity of water to be applied and the time required are chosen according to the type of soil. The application occurs in a previously wetted soil as dry soil severely limits the distribution of water, thus of MS. When possible, the drip line should be buried 5 cm deep.

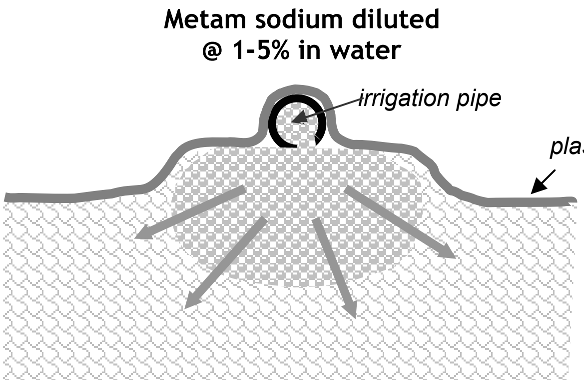

Figure 3

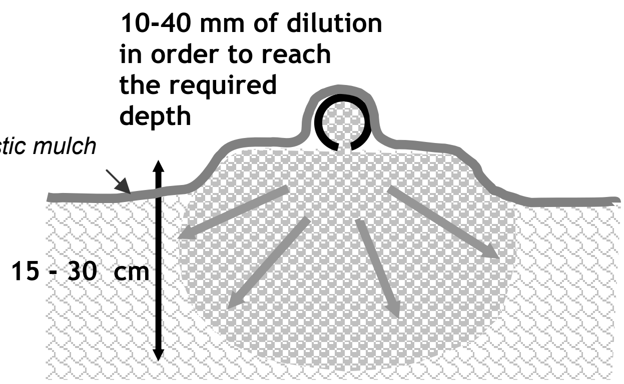

Figure 4

**Sealing of the soil**

When the temperature is particularly high, MITC may evaporate quickly and consequently the efficacy of the treatment can be reduced. The presence on the soil of a plastic film or the application of a few mm of water (3-5mm) 6 hours after the treatment will allow gases to remain longer in the soil. The use of polyethylene film proved to be as efficient as virtually impermeable film when MS is applied by drip-fumigation (El Hadiri *et al.* 2003).

The use of a plastic film resistant to UV, manufactured out of polyethylene or PVC, has the advantage of combining the effectiveness of MS with soil solarisation.

## IMPROVED APPLICATION TECHNIQUES AND COST

Examples of improved application techniques for four crops produced in three countries are shown in Table 1. Improving the application technique for MS not only increases the efficacy but also makes the results of the soil disinfection more reliable. MS applied properly is a cost effective alternative to MB. Improved application techniques for MS should be included in all programmes on alternatives to MB.

Table 1: Examples of improved application techniques for four crops produced in three countries

| Crop | Pest | Country | Rate | Cost of treatment |
|---|---|---|---|---|
| Strawberry | Verticillium | Spain | 1.500 l/ha, drip-fumigation + plastic mulch | 2.250 €/ha |
| Strawberry | Soil fungi | France | 1.200 l/ha, mixing-injection, nursery | 2.400 €/ha |
| Tomato | Nematodes | Spain | 900 l/ha, drip fumigation + plastic mulch | 1.850 €/ha |
| Tomato | Weeds | Spain | 300 l/ha, shallow injection | 650 €/ha |
| Carrot | Nematodes | Italy | 600 l/ha, mixing-injection | 1.500 €/ha |
| Onion | Nematodes | Italy | 900 l/ha, drip-fumigation + solarisation | 1.950 €/ha |

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## IMPROVED TECHNIQUES FOR THE COST-EFFECTIVE APPLICATION OF STEAM AS AN ALTERNATIVE TO METHYL BROMIDE

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### ABSTRACT

Soil steaming has been used since the 1950s when it was used for high-value crops. Since that time modern methods of applying steam have reduced both cost and time without reducing its effectiveness for controlling soil-borne pests and disease. Steam is used mainly in the Netherlands, but also in other countries in Europe such as Belgium and France. Worldwide, steam has replaced methyl bromide (MB) in some parts of Africa where steam is now used in the production of carnation and chrysanthemum cuttings. In Argentina, steam is used in substrate and seeding trays in the tobacco industry as an alternative to MB. Passive steaming is expensive and should be discontinued. Sheet steaming, plate or hood steaming, and bunker steaming are all examples of active steaming techniques which are cost-effective replacements for MB in high-value crops. The techniques for generating steam in each system are discussed.

**Keywords:** Sheet steaming, negative pressure steaming, plate or hood steaming, and bunker steaming, methyl bromide, alternative, cut-flowers

### INTRODUCTION

Steam is used in commercial practice much more commonly than many people are aware. Soil steaming has been used since the 1950s when it was utilised for high-value crops. At that time, each treatment required a lot of digging to place perforated pipes horizontally in the soil. Steam was blown through the pipes after the soil was covered with a sheet. Afterwards the pipes were removed. It required a lot of hard work and took a long time.

Over time, steam treatments have evolved to more efficient methods, from normal sheet steaming to drain steaming (where steam is blown through permanent drains in the soil. The latest versions which are described in this paper are sheet steaming, negative pressure steaming, plate steaming, and bunker steaming for substrates.

Examination of the cost per square meter indicates that steam is normally only suitable for the higher value crops and for crops that not can grow on substrate like chrysanthemum flowers and cuttings, seedbeds for all kind of crops. Steam is also cost-effective for substrates that are not clean (e.g. farm-made mixtures, mixtures with soil, substrates that will be re-used) for nursery bags, potted plants and seed trays.

### USE OF STEAM IN EUROPE AND OTHER COUNTRIES

In The Netherlands, steam systems are used for approximately 1000 ha of chrysanthemum (LEI 2004) for flower production, and nearly 90% of this areas negative pressure steaming. The lifetime of chrysanthemum mother plants is 21 weeks and after each crop the soil has to be disinfested, 2.5 times each year. Steam is also used for a crop like readies, freesias and bulbs. There are 5 contractors that provide steam disinfestation services for growers. Each contractor operates about 4 or 5 mobile boilers. A lot of growers do it with there one heating boiler with is set over from hot water to steam production for this period. ( approximately 70 % of the growers.)

In Belgium, for example, steaming is quite a normal treatment for crops such as chrysanthemum cuttings and other different type cut flowers. It is also sometimes used for tomatoes and melons and seedbeds for all kind of plants.

In France, steam is used frequently for disinfestation of seed beds and in bed culture for special lettuces by plate steaming.

In Africa, in 2003 nearly all the carnation and chrysanthemum cutting production companies in Kenya, Uganda, Tanzania ad South-Africa have converted from MB fumigation to steam with very good results. In total 14 different companies, covering that produce cut-flowers over 110 ha have recently stopped using MB for carnation and chrysanthemum cuttings. The conversions were assisted in many cases by projects carried out by the United Nations Development Programme (UNDP) and the United Nations Industrial Development Organisation (UNIDO).

In Argentina, plate steaming has become quite popular in the tobacco seedbeds in a very large area (Alejandro Valero, UNDP project). In Bolivia and Chile steam has also been adopted for steaming substrate and seeding trays as MB alternatives.

## PRINCIPLES OF STEAM

There are two different principles in steaming - using force and not using force, or active and passive steam applications. The force is used to push or pull steam through the treated soil or substrates. In passive systems, such as normal sheet steaming, steam is merely blown under a thermal sheet laid on the soil and left to move of its own accord. Passive systems are not very efficient and turn out to be very expensive. Equipment and know-how is now available that enables steam to be used very cost-effectively for diverse crops and situations.

In the efficient active systems, various techniques are used to press (push) or suck (pull) the steam through the soil, in order to get a deeper and more uniform distribution. Active systems require a mechanism to push or pull steam through soil, such as perforated pipes in the soil and a fan to pull the steam. The boiler must be selected according to the size and scope of the pipe system and the soil type.

Active and passive systems can use nearly the same amount of energy, but active steaming allows much deeper steaming, up to 60 cm, using the same energy. It needs 25 to 30 kg steam per m², which means 2.4 liters oil (diesel) per m².

In all steaming systems the quality of steam is important. It is essential to produce dry steam. This can be achieved by high pressure or by overheating. The optimal temperature is around 130-160°C. Within this temperature range the steam is really dry and it penetrates easily into the soil.

Another important aspect is the temperature required in the soil in the growing layer – the depth that crop roots grow. In the early days of steam use, it was considered desirable to carry out steam treatments at the highest temperatures for as long as possible. But it is now realized that temperatures higher than necessary waste energy, time and money, and kill many beneficial soil organisms.

High temperatures release excess levels of manganese in the soil which is later bound again by oxygen to the soil, but it wastes time. The same issue arises with nitrogen. But these problems are normally avoided by using lower temperatures. Therefore steam treatments carried out under good agricultural practice today the focus is on modern efficient methods that provide effective lower temperatures (soil pasteurization).

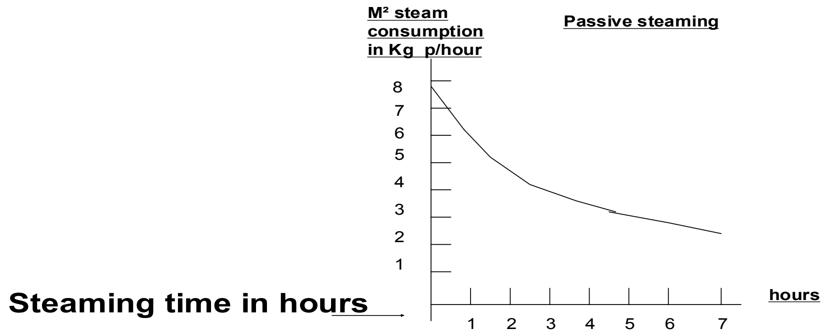
In modern practices, beneficial organisms, such as *Trichoderma* spp., are sometimes added to soil or substrates after steam treatment.

To achieve the correct temperature in the soil it is necessary to prepare the soil in advance. The more open the soil, the better it accepts the steam, leading to better and deeper penetration. Rotary spading equipment removes the plough pan and provides a fine tilth, giving the best soil preparation.

## SHEET STEAMING

In following the condensation of the steam the soil is closed more or less by this action and it lets the steam pass to deep areas. Because of this phenomenon it is impossible to steam deeper than 25 - 30 cm. The steam consumption per hour is much lower as by active steaming. Figure 1 illustrates the principles of sheet steaming.

Figure 1: Sheet steaming

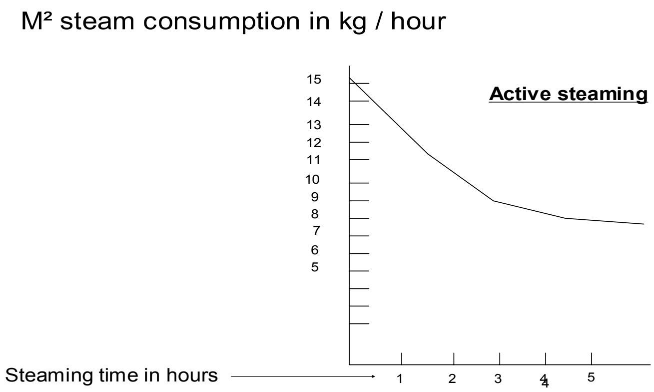



## NEGATIVE PRESSURE STEAM

Negative pressure steaming greatly assists steam to penetrate the soil because it sucks steam deeply into the soil where it condenses quickly. In doing so, it allows the soil to reach the target treatment temperature much more quickly and more effectively.

In this system, perforated drain pipes are buried in the soil at a depth of 60 to 70 cm, at intervals of 3 to 4 m. The pipes are connected to a main drainpipe where there is water divider to drain away the surplus condensed steam (water). A sheet is laid on the soil surface and steam is blown underneath. A ventilator fan at the end of the main pipe creates a negative pressure through the perforated pipes, sucking steam down into the soil. This allows steam to be used more efficiently and makes it effective in many more situations, such as crops with deep rooting systems. Figure 2 illustrates negative pressure steaming.

Figure 2: Negative pressure steaming



## PLATE OR HOOD STEAMING.

A type of hood is placed over the soil or seed bed. The steam is blown under the hood and pressed into the soil. The steam pressure required for this application is between 1 to 3 bar. Approximately 8 to 10 kg steam per $m^2$ which requires 0,8 liter oil (diesel) for each $m^3$. The capacity of the hood is determined by the boiler. Mostly one or two hoods are in place over the seedbed while the next one or two are being prepared.

Plate or hood steaming is used for weed control in forest trees seedbeds and substrates, special lettuce and tobacco seedbeds. This system is mostly used for seed beds for and steaming the upper ten cm. The time required for deep steaming is usually too long. It is possible to use a relatively small mobile boiler. This system is used in Argentina in the tobacco seedbeds.

## BUNKER STEAMING

Bunker steaming also operates with negative pressure system. Drains are laid 60 cm wide and 10 cm deep to suck the steam down. The negative pressure is created by a ventilator. This floor has sidewalls made of stone or wood up 70 or 100 cm.

This system mostly used to disinfest substrate and peat so that they can be re-used within the hydroponic system. It is also used to disinfest seedling trays. For example, it is used in forest tree nurseries in Chile where there are there exist nurseries producing in total more than 30 million seedlings. It is also used in Africa generally for disinfesting lettuce and cabbage seeding trays and substrates used in the production of lettuce and cabbage; and specifically in Kenya and Uganda for disinfestation of cut-flower substrates

A good bunker system uses between 30 to 40 kg steam for 10 $m^3$ substrate or peat. This means 0,33 liter oil ( diesel ) per one $m^3$.

## CONCLUSIONS

Overall, steam is a good alternative to MB for the disinfestation of substrates or soil that is used to produce high value crops. It is also used for the disinfestation of substrates contained in trays for seedling production.

The amount of energy can be minimised through the use of modern techniques to produce the steam. The climate is not significant as steam exists for treatments from Africa up to Bolivia and from Norway to the South of Chile. Steam is environmental friendly and feasible when the correct techniques are used.

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# PRELIMINARY RESULTS OF AN INTERNATIONAL SURVEY ON THE USE METHYL BROMIDE FOR QUARANTINE AND PRE-SHIPMENT

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## ABSTRACT

An international survey was carried out to determine the volumes of methyl bromide (MB) that were used for quarantine and pre-shipment (QPS) purposes in 2002. Preliminary results are presented in this paper. Forty two Parties responded to the survey and reported that 1,611 tonnes of MB was used for QPS. Of this, just over half was used to treat cereals, grains and dried foodstuffs and a further 28% to treat wood packaging, wood and logs. Parties reported widespread availability of alternative treatments, but that cost, location of facilities, and lack of acceptance by trading partners are impediments to their implementation. Although the survey represents a small sample of estimated QPS MB use, the survey has identified the main uses and those uses for which respondents report alternatives are available but not in use. The survey also identified a need for greater awareness of the scope and definition of the quarantine and pre-shipment exemption.

## INTRODUCTION

Applications of methyl bromide (MB) for quarantine and pre-shipment (QPS) purposes are exempt from the phase-out provisions of the Montreal Protocol. Quarantine applications are treatments to prevent the introduction, establishment and/or spread of quarantine pests[10] (including diseases), or to ensure their official control[11]. Pre-shipment applications are non-quarantine applications applied within 21 days prior to export to meet the official requirements[12] of the importing country or existing official requirements of the exporting country.

The Eleventh Meeting of the Parties to the Montreal Protocol instructed the Technical and Economic Assessment Panel (TEAP) "*to estimate the volume of methyl bromide that would be replaced by the implementation of technically and economically feasible alternatives for quarantine and pre-shipment, reported by commodity and/or application"* (Decision XI/12). Due to TEAP workload and other priorities the report requested by the Parties could not be completed. Instead, an international survey on the use of MB for QPS purposes was commissioned to assist TEAP in this work. This paper presents preliminary results of the survey.

## METHODS

In order to standardise data reporting a survey form was developed to gather data from the Parties. In the survey form the broad range of commodities and articles that might be treated with MB for QPS purposes were grouped under 16 headings: Bulbs, corms, tubers and rhizomes (intended for planting); Cut flowers and branches (including foliage); Fresh fruit and fresh vegetables; Grain and cereals for consumption including rice (not intended for planting); Dried foodstuffs (including herbs, nuts, dried fruit, coffee, cocoa); Nursery stock (plants intended for planting other than seed); Seeds (intended for planting); Wooden packaging materials, other packaging materials including cardboard, pallets and dunnage; Wood (including round sawn, sawn wood, wood chips); Whole logs (with or without bark); Hay, straw, dried animal fodder (other than grains and cereals listed above); Cotton and other fibre crops and products; Buildings (including dwellings, factories, storage facilities); Equipment (including used agricultural machinery & vehicles) and empty shipping containers; Personal effects, furniture, crafts, artefacts, hides, fur and skins; Other.

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[10] Pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled.
[11] Control performed by, or authorized by, a national plant, animal or environmental protection or health authority.
[12] Those which are performed by, or authorized by, a national plant, animal, environmental, health or stored product authority.

For each of these major groups, Parties were asked to identify the quantities of MB used for QPS, the reasons for treatment (associated pests, legislative basis for treatment) and the availability of alternative treatments in their country. The survey sought data for the 2002 calendar year as this is the most recent period for which Parties are required to have reported their total MB consumption (including total QPS) to the United Nations Environment Programme (UNEP). The survey form was made available for download from the website of the UNEP Ozone Secretariat from April. The Ozone Secretariat contacted all Parties to the Montreal Protocol and requested that they co-operate in the completion of the survey and that responses be received by 30 June 2004.

## RESULTS OF THE SURVEY

### Volume of methyl bromide used for quarantine and pre-shipment purposes in 2002

Forty two of the 188 Parties to the Montreal Protocol responded to the survey, reporting a total of 1,611,062 kg of MB used for QPS (Table 1). Fifteen of these respondents advised that their use of MB for QPS was zero in 2002 (Colombia[1], Cyprus[1,3], Czech Republic[3], Denmark[2], Dominica[1], Luxembourg[2], Macedonia, Mongolia[1], Namibia[1], Oman[1], Slovakia[3], Slovenia[3], Sweden[2], Togo[1], Uganda[1]). Twenty of the responding Parties operate under Article 5 of the Montreal Protocol, and 22 are non-Article 5 countries. Responding Article 5 countries used 76% of the total MB reported for QPS purposes. Several Parties at the Open-Ended Meeting of the Parties in July 2004 reported that more time was required to complete the survey (Anon, 2004).

TABLE 1: Volume (kg) of methyl bromide used by responding Parties for QPS purposes in 2002

| Name of Party | Total MB (kg) for QPS use | MB (kg) replaceable by alternative technologies | Name of Party | Total MB (kg) for QPS use | MB (kg) replaceable by alternative technologies |
|---|---|---|---|---|---|
| **Bahrain[1]** | 2,000 | 0 | **Myanmar[1]** | 61,373 | 61,373 |
| **Belarus** | 948 | 0 | **Netherlands[2]** | 1,470 | 750 |
| **Belgium[2]** | 25,660 | 25,660 | **New Zealand** | 100,100 | 0 |
| **Bulgaria** | 5,000 | 5,000 | **Nigeria[1]** | 300 | 0 |
| **Cameroon[1]** | 13,500 | 13,500 | **Pakistan[1]** | 31,000 | 0 |
| **Canada** | 18,958 | 8,495 | **Peru[1]** | 36 | 0 |
| **Egypt[1]** | 224,342 | 142,132 | **Poland[3]** | 34,779 | 0 |
| **Estonia[3]** | 100 | 100 | **Portugal[2]** | 5,000 | 5,000 |
| **European Union[4]** | 265,346 | 164,377 | **South Africa[1]** | 44,630 | 9,023 |
| **Greece[2]** | 29,828 | 29,828 | **Spain[2]** | 131,068 | 72,998 |
| **Hungary[3]** | 3,000 | 3,000 | **Turkey[1, 5]** | | |
| **Italy[2]** | 41 | 41 | **United Kingdom[2]** | 34,400 | 27,000 |
| **Jamaica[1]** | 2,828 | 648 | **Uruguay[1]** | 600 | 431 |
| **Mexico[1]** | 284,200 | | **Viet Nam[1]** | 555,900 | 457,300 |
| **Total Article 5 Parties** | **1,220,709** | **684,407** | | | |
| **Total non-Article 5 Parties** | **390,352** | **177,872** | | | |
| **TOTAL** | **1,611,062** | **862,279** | | | |

Notes
1 Operating under Article 5 of the Montreal Protocol.
2 Member State of the European Union in 2002.
3 Current EU Member State, but not a member in 2002.
4 Total of data submitted by current European Union Member States, including those Parties that were not Member States in 2002.
5 Some aspects of the data provided are currently being clarified so are not reported here.

Of the total volume of MB reported for QPS, approximately 75% was used for quarantine (Q) purposes and only 2.7% could be identified as pre-shipment (PS) use. The breakdown between Q and PS use was very similar when totals for Article 5 Parties (74% Q, 3% PS) and non-Article 5 Parties (77% Q, 3% PS) were calculated. The remaining percentages could not be accurately allocated to either category due to ambiguity in the data provided. These figures should be considered preliminary as some survey responses are being clarified with the responding Parties.

### Major sectors using methyl bromide for quarantine and pre-shipment

Just over half of the MB used for QPS in 2002 (Table 2) was used to treat durable food products in the categories of grains and cereals (40.2%) and dried foodstuffs (11.5%). Responding Parties suggested that most of this use of MB (89% and 77% respectively, or 590.8 tonnes) could be replaced by the implementation of alternative technology that is currently available, but not used, in their countries.

The next largest category for QPS use of MB (28.0% or 371.7 tonnes) was for timber and timber products (wood packaging, sawn wood, whole logs), followed by cotton and fibre (6.5% or 86.2 tonnes), and perishable plant products (fresh fruit and vegetables and flowers) at 3.1% or 41.4 tonnes. The category of “other”, the specifics of which were generally not detailed by Parties, represented 6.2% of QPS use.

TABLE 2. Quarantine and pre-shipment use of methyl bromide by use category, including quantities that could be replaced by the implementation of available alternative technology.

| Category (categories are described fully in methods) | MB (kg) | % MB used by sector | MB (kg) for QPS replaceable by alternatives | % MB used for QPS replaceable by alternate technology |
|---|---|---|---|---|
| **Bulbs, corms, tubers and rhizomes** | 3,035.50 | 0.23 | 0.00 | 0.00 |
| **Cut flowers and branches** | 2,731.30 | 0.21 | 2,010.00 | 73.59 |
| **Fresh fruit and fresh vegetables** | 38,682.95 | 2.92 | 16,046.75 | 41.48 |
| **Grain and cereals for consumption** | 533,479.55 | 40.21 | 473,214.00 | 88.70 |
| **Dried foodstuffs** | 152,440.14 | 11.49 | 117,575.00 | 77.13 |
| **Nursery stock** | 64.04 | 0.00 | 0.00 | 0.00 |
| **Seeds for planting** | 618.39 | 0.05 | 400.00 | 64.68 |
| **Wooden packaging materials, pallets, dunnage, other packaging** | 204,612.16 | 15.42 | 119,549.44 | 58.43 |
| **Wood** | 107,791.90 | 8.12 | 100,850.40 | 93.56 |
| **Whole logs** | 59,330.45 | 4.47 | 3,957.80 | 6.67 |
| **Hay, stray, dried animal fodder** | 2,345.00 | 0.18 | 0.00 | 0.00 |
| **Cotton and fibre** | 86,198.00 | 6.50 | 13,500.00 | 15.66 |
| **Buildings** | 0.00 | 0.00 | 0.00 | 0.00 |
| **Equipment** | 35,360.26 | 2.66 | 14,813.00 | 41.89 |
| **Personal effects** | 18,298.65 | 1.38 | 362.25 | 1.98 |
| **Other** | 81,873.50 | 6.17 | 0.00 | 0.00 |
| **TOTAL[1]** | **1,326,861.79** | **100.00** | **862,278.64** | **64.99** |

[1] Note these totals differ from Table 1 totals, because some survey respondents did not allocate total MB into specific categories. Percentages in Table 2 are percentages MB allocated to categories.

### Methyl bromide alternatives

Most Parties reported that MB alternatives were commercially available in their countries. The totals presented in Table 2 suggest that 65% of the MB currently used for QPS purposes could be replaced by technologies that are commercially available in the responding countries. Article 5 Parties estimated that 73% of QPS MB use could be replaced by alternative technologies and non-Article 5 parties reported that 46% could be replaced.

The volumes of MB that could be replaced by alternative technologies within each of the survey categories are presented in Table 2. Responding parties also identified the MB replacement technologies that were available in their countries. For grains, cereals, and dried foodstuffs the available alternatives included phosphine, aluminium phosphide, magnesium phosphide, hot water treatment, heat treatment, controlled atmosphere, and combination hot water and dry air. For timber and timber products alternatives were heat treatment, heat + low $O_2$, phosphine, aluminium phosphide, ethyl formate, sulfuryl fluoride, debarking, insecticides, pest free areas, and inspection. For cotton and fibre, the only alternative reported was phosphine. For perishable plant products alternatives included pyrethroids, cold treatment, hot water treatment, and alternative phytosanitary procedures (pre-clearance programmes, systems approach, pest free areas, inspection). Principle reasons why these alternatives have not been adopted are cost (relative to MB), location of heat treatment facilities, lack of application to packed shipping containers, and their lack of acceptance by importing countries.

**Pests treated with methyl bromide for quarantine and pre-shipment purposes**

For each of the major groups of commodities treated with MB for QPS, the pests that were treated are listed in Table 3, as are the export destination countries that required these treatments to be carried out. The species listed in Table 3 are those specified by responding parties, however many responses were non-specific (e.g., “various insects”). Similarly, the list of countries requiring MB treatment includes all of those countries listed by the responding parties, however in many cases only very general destinations were stated (e.g., “many countries”, “Asia”, “West Africa”). Some Parties expressed concerns that providing details of export destinations was commercially sensitive to some export sectors.

In addition to the export destinations, many QPS treatments were applied by importing countries in response to the detection of quarantine pests during import inspection. These importing countries are not listed in Table 3 as they do not require mandatory MB treatment – the treatments were only applied in response to the detection of specified quarantine pests.

TABLE 3. Key pests treated with methyl bromide for quarantine and pre-shipment purposes in major use categories, and the countries requiring this treatment (2002 data).

| Category | Key pests treated | Countries requiring MB treatment for these commodities [1] |
|---|---|---|
| **Grain, cereals & dried foodstuffs** | *Acarus siro, Ahasverus advena, Araecerus fasciatus, Botrytis spp., Carpophilus dimidiatus, C. hemipterus, Curculio elephas, C. splendana, Cydia* sp.*, Ephestia cautella, Ephestia figulilella, Ephestia kuehniella, Ephestia* spp.*, Fusarium* spp.*, Lasioderma serricorne, Lolium temulentum, , Necrobia rufipes, Oryzaephilus surinamensis, Phoma* spp.*, Plodia interpunctella, Ptinus* spp.*, Rhyzopertha dominica, Sitophilus granarius, Sitophilus oryzae, Tilletia indica, Tribolium confusum, Tribolium* sp.*, Trogoderma granarium, Trogoderma inclusum, Typhaea stercorea,* weed seeds, mites. | Angola, Bahrain, Bangladesh, Canada, China, European Union, Germany, India, Indonesia, Japan, Korea, Macau, Malaysia, Mexico, USA. |
| **Timber products (packaging material, sawn timber, logs)** | *Agrilus planipennis, Anobium rufipes, Anoplophora chinensis, Anoplophora glabripennis, Bursaphelenchus xylophilus, Callidium violaceum, Callipogon relictus, Erwinia salicis, Heterobostrychus* sp.*, Hylastes ater, Ips typographus, Lyctus* sp.*, Lymantria dispar* Asian biotype*, Lymantria monacha, Lymatria mathura, Monochamus alternatus, Monochamus sp., Ophiostoma ulmi, O. novo-ulmi, Phytophthora* sp.*, Phytophthora ramorum, Ptilinus fuscus, Priobium carpini, Sirex noctilio, Tetropium castaneum, Tetropium fuscum, Tomicus piniperda,* | Australia, Brazil, Canada, Chile, China, Cuba, Egypt, Fiji, India, Iran, Ivory Coast, Netherlands, New Caledonia, Mexico, New Zealand, South Africa, Singapore, Spain, |

| Category | Key pests treated | Countries requiring MB treatment for these commodities [1] |
|---|---|---|
| | *Trichoferus campestris, Tyroglyphus farinae, Xanthomonas populi, Zeuzera pyrina*, Anobiidae, Bostrichidae, Buprestidae, Cerambycidae, Curculionidae, Isoptera, Lyctidae, Oedemeridae, Scolytidae, Siricidae, nematodes, wood boring insects, warehouse pests, white ants. | Tanzania, Turkey, USA. |
| **Cotton & fibre** | *Anthonomus grandis.* | European Union, Pakistan |
| **Perishable plant products (fresh fruit & vegetables, cut flowers & branches)** | *Anastrepha fraterculus, Artipus* sp*, Aspidiotus hartii, Brachycera* sp.*, Ceratitis capitata, Contarinia* sp.*, Cydia pomonella, Dypressa ulula, Dysmicoccus neobrevipes, Eriosoma lanigerum, Lepidosaphes ulmi, Palaeopus costicollis, Panonychus ulmi, Planococcus lilacinus, Planococcus pacificus, Pseudococcus citri, Pyrausta* sp.*, Quadraspidiotus perniciosus, Tribolium* sp., Bruchidae, aphids, spider mites, thrips, whitefly. | Bahrain, Brazil, Dubai, Egypt, Japan, Jordan, USA, Yemen. |

[1] As stated by survey respondents

## DISCUSSION

The total amount of MB reported from this survey is approximately 15% of the QPS usage that was estimated for 2000 by MBTOC (2002). Unfortunately, some large users of MB have yet to respond to the survey, so the results need to be interpreted with caution. However there are some general themes worthy of note and which are consistent with the findings of other studies.

The major uses of MB for QPS are for treatment of durable commodities, such as grains, cereals and dried foodstuffs and wooden packaging materials, wood, and logs. Banks (2001) found that these uses were amongst the main QPS uses of MB in Australia in 2000. Similarly, MBTOC (2002) reported that the second largest use of MB (including QPS) after soil fumigation was to treat durable commodities. Most parties reported that alternatives are commercially available for these major groups of durable commodities; however they are yet to be fully implemented. The main impediments to their adoption are cost, location of facilities, and lack of acceptance by trading partners.

Amongst the timber products treated for QPS, wooden packaging is a major area of MB usage. In 2002, an International Standard “Guidelines for Regulating Wood Packaging Material in International Trade” (FAO, 2002) was published. The purpose of the guideline is “to reduce the risk of introduction and/or spread of quarantine pests associated with wood packaging material (including dunnage)” (FAO, 2002) by requiring that such materials are treated before export and marked to indicate that they have been treated. The guideline currently approves only two treatments for this purpose – MB fumigation and heat treatment. Many countries have subsequently acted to harmonise their import requirements with the guideline and it is likely that use of MB for treatment of wood packaging materials will have increased since 2002.

Several responding parties appeared to be unaware of the scope of the exemption for QPS use of MB – 290 tonnes of MB were categorised as QPS when the notes and explanations that were provided by survey respondents indicated that the use was not QPS (e.g., fumigation of flour mills, golf courses and nurseries, requirement of letter of credit). Other Parties reported fumigating export consignments when unaware of the pests being treated or of importing country legislation requiring treatment with MB. Some of these treatments appeared to be prophylactic treatments aimed at ensuring smooth clearance of import inspection procedures, rather than to treat specific quarantine pests.

Although these preliminary results represent a small sample of QPS use of MB, the survey has identified the main uses of MB for QPS, has determined that much more MB could be replaced by the adoption of available alternatives, and that there needs to be greater awareness of the scope of the QPS exemption.

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## ACKNOWLEDGEMENTS

The survey was funded by the European Commission. The author is grateful to the conference organisers for funding his attendance at this conference.

# GLOBAL PROTECTION OF PLANTS AND THE ENVIRONMENT THE INTERNATIONAL PLANT PROTECTION CONVENTION AND QUARANTINE AND PRE-SHIPMENT APPLICATIONS OF METHYL BROMIDE

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## ABSTRACT

Globalisation of plant protection started in 1951 with the establishment of the International Plant Protection Convention (IPPC). The IPPC aims to prevent the spread and introduction of pests of plants and plant products. A disinfestation treatment is sometimes applied prior to export to mitigate the risk of highly-damaging plant pests establishing in new areas. An International Standard for Phytosanitary Measures (ISPM-15) was recently developed to control pests in solid wood packaging material (SWPM) as this is probably the most important pathway promoting the accidental introduction and spread of significant tree pests. ISPM-15 recognises separate applications of heat and methyl bromide (MB) as equivalent phytosanitary management options. The implementation of ISPM-15 globally is stimulating the use of MB for quarantine and pre-shipment (QPS) treatments. Greater reliance on heat, and the substitution of SWPM with plastic, metal and cardboard, may reduce MB use in the long term. The IPPC has recently designated as high priority the drafting of a new ISPM standard entitled "Alternatives to Methyl Bromide". Improved co-ordination between IPPC and the Montreal Protocol would be desirable. In the future new ISPMs will be developed by the IPPC that, given implementation globally, will reduce reliance on MB for QPS applications.

**Keywords:** Methyl bromide, International Plant Protection Convention (IPPC), quarantine and pre-shipment applications, phytosanitary measures, equivalence, international standards for phytosanitary measures (ISPMs).

## INTRODUCTION

Globalisation of plant protection started in earnest in 1951 with the establishment of the International Plant Protection Convention (IPPC). The prime objective of the IPPC is to prevent the spread and introduction[13] of quarantine[14] pests of plants and plant products.

The establishment of the IPPC was triggered *inter alia* by a new invasion of a plant pest in post war Europe. The Colorado beetle (*Leptinotarsa decemlineata*) first invaded France and, despite European efforts to prevent entry, incursions were soon reported from other European countries. Most likely consignments of potato related products from the USA were among the most important pathways for entry and spread of this pest. Despite joint eradication efforts by a number of European countries, the Colorado beetle eventually established and became widespread. A positive outcome was the foundation of a new regional plant protection organisation, the European Plant Protection Organisation (EPPO), for better coordinating eradication efforts in future among European countries. EPPO than prepared the groundwork for the establishment of the IPPC in 1951.

Plant pests are usually small and difficult to detect. Once established in a new area, their impact on local plant communities can be dramatic, as demonstrated by the Colorado beetle. The ability to reproduce, the initial absence of local competitors or predators of the pest, may give plant pests new to an area an added advantage compared to locally-established pests. Most importantly, lack of local knowledge on how to control pests that are new to an area can result in rapid increases in pest populations which are difficult to control and eradicate. As a result, most phytosanitary measures[15] are pre-emptive and put restrictions on consignments of plants or plant products moving in

[13] Introduction as an IPPC term means: the entry of a pest resulting in its establishement (IPPC, newly revised text 1997).
[14] Quarantine pest: A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (ISPM 5: Glossary of phytosanitary terms).
[15] Phytosanitary measure: any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of pests (ISPM 5: Glossary of phytosanitary terms)

international trade that are known to be of 'high' risk for quarantine and other pests. These restrictions often include a pre-shipment application prior to export.

The scope of the IPPC includes protection of wild plants as part of natural ecosystems and habitats. In this respect forests are of primary concern to phytosanitary authorities. The global impact of tree pests is best illustrated by the case of Dutch elm disease (*Ophiostoma ulmi*). This fungus was first introduced in 1930 on unpeeled veneer logs and elm logs from France into North America. It was introduced together with one of the insects responsible for its spread which is known as the smaller European elm bark beetle (*Scolytus multistriatus*). Spread of the disease followed the movement of infected logs via railroads. By 1968, the disease was present throughout the eastern half of the North American continent. Unfortunately, more aggressive forms of the Dutch elm disease fungus were reintroduced from North America back to Europe, most probably between 1970 and 1990, causing massive mortality of elm trees.

Solid wood packaging material (SWPM) is considered one of the most important pathways for the introduction and spread of tree pests. Nearly all (97%) of the quarantine significant tree pests found by port inspectors in the US are associated with solid wood packaging material (Pasek *et al.*). The IPPC has therefore made considerable effort to develop an International Standard for Phytosanitary Measures (ISPM-15) to provide management options for the control of pests in SWPM. The development of this and other measures is described.

## PHYTOSANITARY MEASURES

Countries have two options for putting in place phytosanitary measures while taking into account international agreements. Measures can be based on a Pest Risk Analysis (PRA)[16] or they can be based on International Standards for Phytosanitary Measures (ISPMs)[17]. Standard setting within the framework of the International Plant Protection Convention started in 1995.

An important impulse for standard setting was the establishment of the WTO Agreement on the application of Sanitary and Phytosanitary Measures (SPS Agreement). The SPS Agreement recognised standards generated by the so-called three sister standard setting bodies, notably the International Office of Epizootics (for animal health concerns), the Codex Alimentarius Commission for food safety issues, and the IPPC for phytosanitary issues.

Since 1995, 21 ISPMs have been adopted providing guidance on issues such as export certification systems and import regulatory systems[18]. At present one specific commodity standard has been developed in the IPPC framework, notably guidelines for controlling pests in SWPM in international trade (ISPM 15) which was adopted in 2002 by the governing body of the IPPC.

## THE BIRTH OF AN INTERNATIONAL PHYTOSANITARY STANDARD FOR SOLID-WOOD PACKAGING MATERIAL

The pinewood nematode (*Bursaphelenchus xylophilus*) has been an important driving force for global harmonisation of measures for wood packaging material. This nematode is probably native to North America where it causes significant damage mainly in introduced pines. In Japan, the pest is known for dramatic annual losses of trees varying in volume from about 500,000 $m^3$ to a high of 2.4 million $m^3$ in 1979[19], depending on efforts for pest suppression. Heavy losses were also reported in China in the 1990's. Outbreaks of the pest were also discovered in Korea in 1992.

[16] The process of evaluating biological or other scientific and economic evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it (IPPC, 1997, revised text)
[17] Standard: Document established by consensus and approved by a recognized body, that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.
[18] For an overview of all ISPMs, see the International Phytosanitary Portal (http://www.ippc.int/IPP/En/default.htm)
[19] Mamiya. Y, 1983. Pathology of the pine wilt disease, *Bursaphelenchus xylophilus.* Annual review of Phytopathology 21: 201 – 220.

Because of these developments, pinewood nematode has been a prominent quarantine pest for the European Community since the harmonisation of legislation of Member States of the European Community in 1992. Following repeated interceptions of pinewood nematode and its vector the insect *Monochamus alternatus*, the EC stepped up its measures in succeeding years. These measures were challenged *inter alia* by North America, claiming that the climate would not support the establishment of the pinewood nematode or its vector in Europe. An extensive pest risk analysis was completed indicating that pinewood nematode may indeed be capable of establishment notably on the Iberian Peninsula, including Spain and Portugal. Unfortunately, pinewood nematode was first discovered in Portugal in 1999, and since that time Portugal has tried to eradicate and contain the pest, with annual costs exceeding €1,000,000.

Meanwhile, North America was struggling with outbreaks of another aggressive pest attacking non-coniferous trees, the Asian longhorned beetle *(Anaplophora glabripennis)*, which is also considered a quarantine pest for the European Community. An extensive pest risk analysis undertaken by US authorities revealed that SWPM was the most important pathway for the introduction and spread of the longhorned beetle and other tree pests[20].

Because SWPM may circulate in international trade for a great many years and the true origin is often difficult to determine, it was soon recognised that phytosanitary measures should be applied worldwide. An FAO expert working group developed a draft ISPM in 2001. The key treatment, which was first identified as being effective against various quarantine pests, including pinewood nematode, was a heat treatment. Heat was claimed to have a permanent effect as attractants to live wood pests would evaporate, thereby reducing the chances of re-infestation following treatment. As an alternative to heat, the draft text also included the possibility of using methyl bromide (MB). MB has the disadvantages of being an ozone depleter and of not evaporating the attractants in the wood.

Meanwhile, the EC stepped up its measures against products imported from China with SWPM at the end of 2001 because of continued interceptions of life pests on consignments originating from China. The Chinese quarantine authorities have increasingly relied on the use of MB fumigation of consignments containing SWPM for exports to the United States and Europe.

Following an extensive review of scientific literature and on the basis of new research activities, the FAO expert working group recognised heat or MB treatment of SWPM were suitable for killing all significant quarantine pests. The main risk to be tackled would be to ensure treatment of SWPM following its manufacture. Once SWPM is circulating in international traffic, the chances of re-infestation are limited because SWPM does not often end up adjacent to forest areas where most quarantine pests live. As such, ISPM-15 was adopted in March 2002 allowing the use of heat and MB as equivalent[21] phytosanitary management options. Moreover, SWPM when treated following ISPM-15 could be stamped to designate treatment origin and to indicate that a treatment had been applied.

## ISPM-15 INCREASES GLOBAL METHYL BROMIDE USE

Exporting countries have tended to implement ISPM-15 in order to ensure compliance with the requirements of the importing country for consignments containing SWPM. This implementation has stimulated the use of MB for QPS. Non-industrialised countries use QPS-MB as heat treatment chambers and accompanying technology are less available in these countries. Industrialised countries with large volumes of containers from different origins moving on to new destinations also face difficulties in importing consignments that contain SWPM.

In the future, an increasing number of countries are putting in place export certification systems, allowing MB-free treatment of SWPM. SWPM may also be substituted with plastic, metal and cardboard.

[21] Principle of equivalence: countries shall recognize as being equivalent those phytosanitary measures that are not identical but which have the same effect (ISPM 1 Principles of Plant Quarantine as related to international trade)

However, it is likely that MB will still be needed in the short term following pest interceptions at ports of entry, or for the treatment of shipping containers in the case of non-compliance with ISPM-15. The only alternatives are often destruction of the consignment or redirection to the country of origin which are not viable management options in the framework of the WTO.

## CONCLUSIONS AND FUTURE OUTLOOK

In the future many new commodity-specific ISPMs will be developed by the IPPC that will include a range of treatment options which will help to reduce reliance on MB for QPS treatments. A newly identified priority for an ISPM to be developed, as designated by the governing body of the IPPC, is entitled "Alternative Strategies to Methyl Bromide". The use of MB will decrease as countries acquire the technology to implement non-MB treatments. This process could well be facilitated with greater cooperation between representatives from the IPPC and the Montreal Protocol.

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# PRACTICAL ALTERNATIVES TO METHYL BROMIDE FOR USE AS QUARANTINE AND PRE-SHIPMENT TREATMENTS IN NORTH AMERICA.

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## ABSTRACT

We present recent advances in quarantine and pre-shipment alternatives: phosphine and methyl bromide recapture for empty ship holds; radio frequency heating in walnuts; low oxygen followed by low oxygen, cold or virus treatment to disinfest dried fruits and nuts; controlled atmosphere temperature treatment system (CATTS) for fresh fruit.

**Keywords:** insects, QPS, control atmospheres, heat, cold, irradiation.

## INTRODUCTION

For most countries methyl bromide is still the method of choice to deal with quarantine pests. As quarantine and pre-shipment (QPS) treatments are exempt under the Montreal Protocol, there has been less research into developing alternative treatments. However, the European Community has capped its use of methyl bromide in 2001, and it has committed to reducing its QPS consumption. There are concerns that methyl bromide will eventually be unavailable for QPS because of regulatory restrictions, or the cost will become too expensive. Hence there is an interest to develop alternatives for QPS uses.

Quarantine uses of methyl bromide are distinct from other methyl bromide uses in that they are mandated by government authorities, against a pest that could be introduced to the receiving country or region. Therefore the level of control required is much greater than regular treatments in places such as flour mills or strawberry fields. Pre-shipment uses of methyl bromide are defined as uses of methyl bromide done within 21 days of export, mandated by government authorities and are required to maintain the quality of the product. Detailed definitions are found in the 2002 Methyl Bromide Technical Options Report.

In 2000, globally about 20% of methyl bromide was used for QPS treatments; durables (2100 mt), timber (3900 mt) and perishables (4500 mt) (MBTOC 2002). The non-QPS uses for the USA in 1997 was 20,520 mt, QPS in the USA is only about 1% of total use. In Canada the non-QPS uses were 142 mt, making QPS in Canada about 8% of total use. In Canada in 2003, 17 mt were used for QPS, 75% of this being used for commodities imported into Canada, the other major uses were; empty grain ships (8%) or export (14%). The USA used 260 to 294 mt/yr between 1996 and 1998 (Vick & Schneider 2002), with about equal amounts being used for export and import. The following uses were recorded for export; fruits and nuts (50%), dunnage (19%, this is known to be underestimated), logs (17%) and cotton (11%). The main uses listed for imported goods are; fruit (56%), cotton (11%) and vegetables (12%).

Some common QPS treatments that do not use methyl bromide are: irradiation, heat, cold, systems approach, pest free zones/seasons, controlled atmospheres, physical removal and other chemicals. There have been a number of recent reviews of alternatives to methyl bromide for QPS treatments (Dowdy 2002, Fields & White 2002, MBTOC 2002), so we have limited the information presented here to some recent advances in the field.

## EMPTY SHIP HOLD TREATMENTS

In Canada, grain is exported with zero tolerance for live grain-feeding insects. To this end, it is illegal to transport grain in vessels (trucks, rail cars or ships) that are already infested. Ships are inspected before grain is loaded into the holds. On average there are 1000 grain ships inspected each year and about 20 ships a year are fumigated with methyl bromide because of infestations. Methyl bromide is used because it is effective; rapid (reducing the demurrage charges which can be $10,000/day), and works at low temperatures.

Three alternative methods were tried in an empty ship; cylinderized phosphine ($ECO_2FUME$, 2% $PH_3$, with 98% $CO_2$), phosphine generator ($MgPH_3$ powder) and methyl bromide with recapture after the fumigation. Phosphine, a common grain fumigant, is usually applied as tablets of $AlPH_3$ , but this method is much slower than methods we used. The final concentrations were 500 ppm $PH_3$ for the $ECO_2FUME$, 1000 ppm $PH_3$ for the phosphine generator, and 5400 ppm of methyl bromide for the methyl bromide recapture test. Four common stored grain insect pests (red flour beetle, *Tribolium castaneum;* rice weevil, *Sitophilus oryzae*; lesser grain borer, *Rhyzopertha domincia*; rusty grain beetle, *Cryptolestes ferrugineus*) were placed in vials in the ship holds, 25 adults, and an unknown number of eggs had been laid in the grain.

All adults died within 32 hours in all of the treatments. No red flour beetles eggs were alive after 32 hours exposure. The phosphine treatments controlled at least 94% of the rice weevil and lesser grain borer eggs after 32 hours, 99% after 48 hours and 100% after 72 hours (Fields & Jones 1999).

Air from the ship hold treated with methyl bromide was pulled through a zeolite bed at the end of the fumigation. Zeolite can hold 4-6% of its weight in methyl bromide. Over 80% of the methyl bromide was captured on the sieve. No extra time was needed to capture the methyl bromide as compared to venting. Advantages of recapture are; less methyl bromide vented, less hazard to workers and little change from present practice of methyl bromide fumigation.

## RADIO FREQUENCIES TO CONTROL INSECTS IN WALNUTS

Codling moth (*Cydia pomonella*), navel orangeworm (*Amyelois transitella*) and Indianmeal moth (*Plodia interpunctella*) are common insect pests in walnuts in California, USA. Currently, successful export of in-shell walnuts requires treatment with methyl bromide before shipment. However, except for product destined for Japan, methyl bromide fumigation of walnuts is not considered a quarantine treatment. We felt that heat treatments described here may have potential both for quarantine and non-quarantine treatments.

Radio frequency (RF) has been used for drying and heating in numerous industries, including textiles, food processing, woodworking, paper processing and plastics. Industrial radio frequencies range from 10 to 100 MHz. Unlike X-rays and gamma rays that can alter molecular structures, RF is “non-ionizing” radiation, heating product much like microwave radiation. Because RF treatments rapidly heat product throughout, insecticidal temperatures are more easily reached without causing product damage.

Walnuts were heated with RF at $5^oC$/min. to 47, 50, 53 and $55^oC$ causing 32, 77, 99 and 100% mortality respectively of fifth instar navel orangeworm. This insect and stage were chosen because it was the most heat tolerant of the possible pests. Heating with RF caused no adverse effects on walnut quality (Mitcham et al. 2004).

## COMBINATION OF LOW OXYGEN FOLLOWED BY PREVENTIVE TREATMENTS

Pyralid moths are a major problem in dried fruits and nuts in California, USA. Navel orangeworm and raisin moth (*Cadra figulilella*) infestations begin in the field, though these pests do not reproduce in storage. The Indianmeal moth populations increase with time in storage if not held in check by control methods. A non-chemical treatment schedule was designed to address these various pests (Johnson et al. 1998, 2002).

Initial disinfestation of the navel orangeworm and the raisin moth was carried out by treating commercially harvested almonds (lots of 227 kg) , walnuts (lots of 225 kg) or raisins (lots of 1800 kg) with 0.4% oxygen for 6 days at $25^oC$. This treatment was followed by one of three preventive treatments; 5% oxygen, cold storage at $10^oC$ or treatment with Indianmeal moth granulosis virus. Indianmeal moth adults were released weekly into the treatments.

The initial low oxygen disinfestation reduced populations of navel orangeworm and raisin moth between 100 and 90%. Indianmeal moth developed rapidly in the untreated products, with pheromone traps catching between 50 and 800 adults/week. A total of less than 22 adults were found in the low oxygen and cold storage during the entire trapping period (13 – 40 weeks). These adults were probably coming from outside the test enclosures, as no damage or larvae were found in the product. In the treatment with granulosis virus, there was a low level of moths trapped and larvae found in the product, 10% or less than in the untreated product (Johnson et al. 1998, 2002).

## COMBINATION HOT FORCED AIR WITH CONTROLLED ATMOSPHERES

A collaborative project with Elizabeth Mitcham (University of California, Davis), Lisa Neven (USDA-ARS in Wapato, WA) and Dan Black (Techni-Systems, Chelan, WA) developed a research unit that can treat commodities with hot forced moist air or vapor heat while monitoring and controlling the rate of heating, surface and core temperatures, relative humidity, dew point, air speed, oxygen and carbon dioxide levels (Neven & Mitcham 1996). They called this technology CATTS for Controlled Atmosphere Temperature Treatment System, and is similar to system developed in New Zealand. There are now research-scale CATTS units in Washington, California, Hawaii, Texas, Mexico and Israel. A 2-tonne commercial scale unit is being tested in George, WA.

CATTS was developed to exploit the differences in stress responses of plants versus insects to control insect pests without damaging fruit. A heat shocked plant is more resistant to chilling than one which never received a heat shock (Neven et al. 1993). Insects, on the other hand, do not generally exhibit this response scenario. In addition, plants are more tolerant of low oxygen environments than are insects.

Traditionally, heat treatments have been conducted to reach the target temperature as quickly as possible. This strategy works effectively for tropical and sub-tropical fruits, but not for temperate tree fruits (Neven et al. 1996). The lower limit of the optimal rate of heating for apples and pears reflected the heating rate of the fruit on the tree during a hot summers' day. Fruit can respond to the heat load in a direct postharvest treatment if it is not far from the cyclical heat load experienced during the growing season. While heating rate needs to be optimized to preserve fruit quality, the effects on insect mortality are also paramount. The slower the rate of heating, and the lower the final treatment temperature, the longer the total treatment needs to be to control the insect pest (Neven et al. 1996). A treatment matrix for codling moth mortality and apple quality that incorporates heating rate, final treatment temperature, and duration was developed (Neven & Drake 2000). This guideline was used to develop combination treatments for apples, winter pears, peaches, nectarines and Bartlett pears.

Fruit and insects were subjected to heat treatments with and without controlled atmospheres (CA) (1% $O_2$, 15% $CO_2$) with a linear heating rate of 12°C to final treatment temperatures of either 44 or 46°C for 4 or 3 hours. Dew point was controlled to 2°C above the surface temperature of the fruit. Air speed was maintained between 1.5 and 2.0 m/s. Codling moth larvae (fourth instar), the stage most tolerant to heat and controlled atmosphere treatments, were transferred to the fruit 24 hours prior to the test. Codling moth infested fruit were evaluated the day after treatment and moribund larvae were held on artificial diet for 7 days and evaluated for survival. Following treatment, all fruit that were to be evaluated for quality were stored under standard CA conditions (1% $O_2$, 1% $CO_2$, 0°C) for 0, 45 or 90 days. No significant differences were detected in fruit quality for fruit heated in air or under CA conditions. In all heat-treated fruit, quality after cold storage was as good or better than fruit that were not heat-treated. The results from this test were similar to those obtained in previous studies using fruit heated in air (Neven & Drake, 2000).

The impact of application of the controlled atmosphere during the heat treatment on insect mortality is significant. Heat treatments without the addition of the controlled atmosphere gave 55% mortality of the fourth instar codling moth after 3 hours of treatment (using the 46°C treatment), whereas heat treatment accompanied with a controlled atmosphere gave 100% mortality.

Successful research scale trials have been carried out on: sweet cherries with codling moth and Western cherry fruit fly; peaches and nectarines with codling moth and Oriental fruit moth; mangoes in Mexico for fruit flies.

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# OVERVIEW OF ALTERNATIVES FOR THE DISINFESTATION OF SOLID-WOOD PACKING MATERIAL

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## ABSTRACT

In international trade there is a high risk of spreading of invasive forestry pests with solid wood packing material (SWPM). Detections of forestry pests in the port of Hamburg are described. The International Standard for Phytosanitary Measures No. 15 (ISPM No. 15) is possibly a good instrument to minimize problems with infested SWPM. So far only heat treatment and fumigation with methyl bromide are approved measures in ISPM No. 15. Alternative treatment methods have to be approved soon. An overview of such methods and requests for treatment of SWPM is given.

**Keywords**: forestry pests, solid wood packing material, ISPM No. 15, alternatives, methyl bromide

## INTRODUCTION

One result of an intensive cargo handling between countries with similar climatic conditions is a successful spread of different kinds of invasive pests. A cause of the numerous introductions of such organisms in different countries is the increase of containerization in the transport of general cargo. As an example 96.1% of the trans-shipment of general cargo in the port of Hamburg in 2003 was transported in containers. This is a difficulty for the plant health services at the points of entry, because a completly and professionally carried out phytosanitary inspection of a consignment in most cases is only possible after unloading, which often should not take place before reaching the place of destination in the inland.

Especially in the case of solid-wood packing material (SWPM) the risk of introductions of non-indigenous forestry pests is very high. On the one hand at least in two of three containers there can be found SWPM, on the other hand in contrast to timber consignments the packing wood which is used for certain goods often is in a very poor quality and sometimes also infested with forestry pests. There are regular notifications of EU-member states because of interceptions of SWPM containing different kinds and stages of forestry pests. As a result of this and as a consequence of the repeated introductions of the Asian Longhorned Beetle *Anoplophora glabripennis* Motschulsky (ALB) from China into the USA the first reaction of the EU was decision 1999/355/EC which shall protect the Community against infestations of ALB. Under this decision all SWPM made of hardwood with origin in China has to be free from bark and insect bore holes greater than 3 mm or kiln-dried to below 20% of moisture content.

The reason for a second decision which was adopted in 2001 (2001/219/EC) was the introduction of the pine wood nematode *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle (PWN) to Portugal in 1999. Coniferous SWPM from Japan, Canada and USA which is introduced into the EU has to be marked and treated in one of the following ways: heat-treatment, fumigation or chemical pressure impregnation, for coniferous SWPM with origin in China a phytosanitary certificate has to be issued, a treatment is necessary when the wood has its origin in regions where PWN occurs. There are also large varieties of other pests which are affected by EU-quarantine regulations, e.g. non-European bark beetles and *Pissodes* sp. in conifererous wood, fungi like *Atropellis* or *Ceratocystis* species and not least non-indiginous *Monochamus* species as the vectors of PWN.

All member states had to set out a plan for the monitoring of ALB and PWN. For that purpose the plant health service in Hamburg has a strong cooperation with the customs authorities and port economics.

As a result of the intensive inspections of SWPM in Hamburg there has been detected a variety of wooden pests in the past decade as presented in TABLE 1, some of them with quarantine status in the EU.

Another difficulty in preventing the introduction of forestry pests is the hugh amount of containers which are transported through our ports daily. For example the transshipment of containers in the port of Hamburg increased from 5.4 million TEU (transport equivalent unit = volume of a 20'-container) in 2002 to 6.1 million TEU in 2003. At least 1.35 million TEU of these containers were transshipments with the People's Republic of China (ca. 1 million TEU in 2002), that country from which most detections of forestry pests in SWPM could be counted.
At sight of such figures it is conceivable that phytosanitary inspections of SWPM can only have spot check-like character. At a rough guess, there has been inspected not more than 0.2% of the consignments with SWPM from China, Japan, Canada and USA in Hamburg in 2003. The situation in most other countries is comparable. In the USA less than 1% of imported SWPM are inspected by American Plant Health Inspection Service (Berendes & Pehl 2003).

TABLE 1: Detections of introduced wooden pests in the port of Hamburg between 1991 and July 2004

| Systematic classification | Number of consignments | Comments |
|---|---|---|
| COLEOPTERA | | |
| Anobiidae | 3 | |
| Bostrychidae | 25 | Frequently detected in consignments from India |
| Cerambycidae | 49 | Many dectections in consignments with granite from China 2x *Anoplophora glabripennis*, 1x *Monochamus alternatus* |
| Lyctidae | 9 | |
| Oedemeridae | 1 | |
| Platypodidae | 1 | |
| Scolytidae | 3 | |
| HYMENOPTERA | | |
| Siricidae | 3 | |
| ISOPTERA | | |
| Rhinotermitidae | 1 | |
| NEMATODA | | |
| Parasitaphelenchidae | 1 | *Bursaphelenchus mucronatus* from China |
| not determinated | 2 | 1x phytophageous, 1x saprophytic |

## INTERNATIONAL STANDARD FOR PHYTOSANITARY MEASURES NO. 15

On the basis of the situation described above adoption of "*Guidelines for regulating wood packaging material in international trade*" (ISPM No. 15) possibly is a good instrument to minimize problems with infested SWPM. All signatory countries and even non-signers of the International Plant Protection Convention (IPPC) have now the possibility to adopt the regulations of ISPM No. 15 in their quarantine regulations for packing wood. The aim is that one day most SWPM used in international trade, will be produced by manufacturers registered in an export certification system and contains an appropriate mark with the possibility of tracing back the origin. At the moment there are only two approved methods of treating SWPM listed in Annex I of the standard:

- Heat treatment with a minimum wood core temperature of 56°C for a minimum of 30 minutes (other methods like kiln drying or chemical pressure impregnation may considered heat treatments to the extend that they meet the heat treatment specifications)
- Fumigation with methyl bromide (MB) according to a minimum temperature/dosage/time-correlation given in Annex 1 of the standard.

It is obviously disadvantageous that ISPM No. 15 actually only allows MB fumigation as an approved alternative for heat treatment. In Annex III of the standard a variety of other treatment methods is listed (TABLE 2), but these are only approved, when it can be demonstrated that they provide an appropriate level of phytosanitary protection. National Plant Protection Organisations (NPPOs) should be aware that measures may be added or changed and should have sufficiently flexible import requirements for SWPM to accommodate changes as they are approved.

Treatments being considered and which may be approved when appropriate data becomes available, include but are not limited to:

| Treatment | Single methods |
|---|---|
| Fumigation | Phosphine, Sulfuryl fluoride, Carbonyl sulfide |
| Chemical Pressure Impregnation (CPI) | High pressure/vaccuum process, Double vaccum process, Hot and cold open tank process, Sap displacement method |
| Irradiation | Gamma Radiation, X-rays, Microwaves, Infra Red, Electron beam treatment |
| Controlled atmosphere | |

Of course, NPPOs may accept any measures other than those listed in Annex I by arrangement with their trading partners, but actually no other methods are accepted by countries which already adopted ISPM No. 15 in their phytosanitary import regulations. The EU prospectivly will adopt the standard in Guideline 2000/29/EC on 01 March 2005, so far no alternative methods are planned to be acknowlegded. This will very possibly lead to an increase of fumigations with MB in the near future. Here it must not be forgotten the lack of heat treatment facilities in many developing countries. In contrast to this there probably will be no more possibility to use MB for export treatments in the EU after September 2006, because no company applied for an admission of this active substance in the annexes of directive 98/8/EC so far. The only possible use after that date would be for emergency measures. Therefore it is extremly important to approve other treatment methods for the standard in the near future.

As already mentioned an approval of alternative treatment methods of SWPM is only possible after demonstration that they possess an appropriate level of phytosanitary protection. The evaluation of these methods is one task of the recently founded international working group, the "International Foresty Quarantine Research Group" (IFQRG). In February 2004 the first official meeting of this expert group (scientists, employees of NPPOs) took place in Rome. IFQRG is an advisory body to the IPPC providing scientific analysis and review of global phytosanitary issues and new information. Furthermore the group is a forum for the discussion and clarification of key issues related to the phytosanitary implications of global trade. Another task is to identify and undertake collaborative scientific research aimed at high priority forestry quarantine questions.

For that purposes diffferent working groups are dealing with the following sectors: Development of testing criteria for alternative treatment methods of SWPM; heat treatment; fumigation; Chemical pressure impregnation; Radiation; International data base for phytosanitary interceptions.

The following criteria were laid down by IFQRG to meet the requirements of IPPC No. 15:

- Effective (100% killing rate) on all kinds of quarantine pests: insects, nematodes, fungi
- Effective on all stages of development: eggs, larvae, pupae, adults, spores, mycelium, resistent stages
- Effective in all species of wood
- Effective in all standard wood sizes which are used in international trade (up to 10 cm)
- Effective at any moisture content of the wood
- pests have to be killed on, inside and in the bark as well as in the wood

Additionally there are other factors which can result in a limitation of the broad use of alternative treatments. These factors can be influenced by economic considerations or else depends on authorisation of single treatment methods in each country. Such factors can be:

- Areas of application: Is an alternative treatment limited to stationary use or can it also be used in transport units (e.g. containers)? Which dimensions of wood can be treated?
- Operators safety: How high has the standard of safety measures to be, especially in case of fumigation or irradiation methods?
- Safety of persons[22] in countries of destination: When containers have been fumigated for export, they have to be degassed prior to departure, otherwise marking according to regulations of International Maritime Organisation (IMO) is necessary. It is proven that in many cases containers without markings contain fumigant residues, partially in concentrations exceeding MAC value. An extensive and detailed study on this was carried out in the port of Rotterdam (Knol-de Vos 2002). Causes of such residues are far to short degassing times or even fumigations without any degassing. Because port authorities in Europe are well informed about this problem, as a precaution containers are degassed at arrival prior to customs clearance. This often leads to delays. On a long-term basis this can make fumigation methods for SWPM unattractive.
- Environmental effects: Air, water, soil, biota
- Costs of an alternative method: As experience with heat treatment shows, the costs for a treatment method after establishment on the market are reduced in the long term. To achieve sufficient demand for a new kind of treatment, costs should not be many folds higher than that of other methods. Interesting are also additional costs, e.g. transport costs in case of container fumigations.
- duration of application: Often consignments have to be delivered just in time, for this cases applications and – when necessary – degassing should not take to long.
- Chemical and physical properties: Corrosivity, absorption by fat, oil etc., reactivity with different kind of materials, production of objectionable colourations or odours and others.

There are promising alternative treatment methods in different areas in development or already developed. It would be desirable, that they are established in Annex I of ISPM No. 15 soon.

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[22] Customs and other port authorities, employees of cargo handling and warehousing facilities

# LEADING METHYL BROMIDE ALTERNATIVES IN COMMERCIAL USE FOR TOMATO PRODUCTION IN DIFFERENT ALL GEOGRAPHIC REGIONS EXCEPT THE UNITED STATES

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## ABSTRACT

Many alternatives (non chemical and chemical) to methyl bromide (MB) are available and have proven to be, when associated with an Integrated Pest Management Program, as efficient as MB for the control of soil borne pathogens of tomato in different geographic regions. Developing countries will be able to phase out MB before the date scheduled in the Montreal Protocol of 2015. In 2003 and 2004 respectively, only 5 and 3 developed countries have requested MB critical use exemptions after 1 January 2005 for tomato production. This reduction in one year of 60% of countries requesting critical use exemptions illustrates the availability at a commercial level of efficient alternatives to methyl bromide for tomato production.

**Keywords**: integrated pest management, methyl bromide, alternatives, critical use exemptions

## INTRODUCTION

Methyl Bromide (MB) is a powerful ozone depleting substance. The meeting of the parties (MOP) to the Montreal Protocol called for its phase out in 1992. In 1997, a global phase out schedule of this chemical was established by the MOP according to which developing countries are required to freeze consumption and production of MB by 2002, reduce its use by 20% in 2005 and complete total phase out by 2015. In comparison, developed countries must phase out most uses of MB by 2005 (Batchelor 2002). What is the current situation in developing and developed countries? Are there technically available and economically feasible alternatives for tomato in the two most important production systems in Europe and in the Mediterranean region? If so, what are the main constraints preventing their adoption at a commercial level? This paper deals with leading alternatives to MB for tomato production in different geographic regions, except in the United States which is reported separately by Gilreath (2004).

## TOMATO PRODUCTION SYSTEMS AND ALTERNATIVES TO METHYL BROMIDE

There are two models for tomato production in Europe and in the Mediterranean area. The Netherlands, Belgium, United Kingdom, Denmark and Germany primarily use the "Dutch system" in which tomatoes are cultivated in green houses, mainly on substrates such as rockwool, with a central hot water heating system and computerized control of environmental parameters and the watering system. The Mediterranean system is different from the Dutch system and is characterized by cultivation mainly in soil under plastic or mesh covered green houses or walking tunnels lacking temperature or atmospheric control. In this system, soilless cultivation is done on a small scale (Tello 2002).

Therefore, in the Dutch system, the main alternative to MB is soilless culture in association with other alternatives e.g. resistant cultivars and grafting. In the Mediterranean system, there is no single alternative, but a combination of alternatives selected according to their suitability to the cropping system (rotation, cultivars used, economic value) the environmental conditions (temperature, pest distribution and pressure) and the regulatory aspects in the country.

## USE OF METHYL BROMIDE FOR TOMATO PRODUCTION IN EUROPE AND IN THE MEDITERRANEAN REGION

In some European countries (e.g. Spain, The Netherlands, Germany) and North African countries (e.g. Tunisia) MB is not used to control tomato soil borne pathogens (Table 1). Spain has the same production system, climate, pest pressure and environment as Portugal, Southern France, Italy or Greece which still consider that MB is important for tomato production. The characteristics of tomato production in The Netherlands are similar to those in neighbouring Belgium (Pauwels 2002) which still uses MB while The Netherlands has phased out this product many years ago. In Spain and in The Netherlands many alternatives have effectively replaced this fumigant (Bello *et al.* 2002, Tello 2002 MBTOC 2002). In Tunisia, MB has never been registered as fumigant for soil disinfestation. It is used only for durables and particularly for date disinfestation. In Morocco, MB is still widely used by tomato growers (Besri 2002, 2003).

Table 1: Examples of some European and Mediterranean countries using and not using methyl bromide for Tomato production

| Methyl Bromide | Developing countries | Developed countries |
|---|---|---|
| Used | Morocco, Egypt Jordan, Lebanon, Turkey, | Portugal, France, Belgium, Italy, Greece, |
| Not Used | Tunisia | Denmark ,Spain, Holland, Germany |

## LEADING ALTERNATIVES TO METHYL BROMIDE FOR THE CONTROL OF TOMATO SOIL BORNE PATHOGENS IN DEVELOPING AND DEVELOPED COUNTRIES

The leading alternatives to MB for the control of tomato soil borne pathogens include non chemical alternatives (resistant cultivars, grafting, biofumigation, soilless culture, biocontrol, physical treatments) and chemical alternatives (chloropicrin, 1,3-D, Dazomet, Metam Sodium) and a combination of these treatments (Table 2). The successes of the alternatives depend on their use within an IPM program that includes sanitation, pathogen free seeds and seedlings and other production methods. In general, the results obtained at experimental and commercial levels using these alternatives are as good as those obtained with MB for soil disinfestation (MBTOC 2002).

*Developing countries*

In developing countries, 66% of MB is used for soil fumigation of which 23% is for tomato production (MBTOC 2002). In order to phase out MB in developing countries, the Multilateral Fund (MLF) is providing these countries with financial and technical support. Many demonstration and investment projects have been implemented to limit the use of MB in tomato production in Latin America (Argentina, Chile, Dominican Republic, Guatemala, Mexico, Uruguay), Africa (Botswana, Egypt , Morocco ), Middle East (Jordan, Lebanon ,Syria, Turkey) and Asia (China). The alternatives tested in these tomato projects are non chemical (resistant cultivars, grafting, solarisation, steam, soilless culture, biological control) and chemicals (Dazomet, 1,3-D, Metam Sodium) and a combination of these treatments (Table 2).

The main activities of the demonstration projects include trials to evaluate and adapt alternatives to the local conditions, workshops with stakeholders and dissemination of information to raise awareness of MB reduction and phase out (MBTOC 2002, Minuto *et al* 2003b, Amadio 2004). Because of the excellent results obtained in the demonstration projects, a quick and enthusiastic response has come from many developing countries promising an earlier phase out of MB. Therefore, it is expected that in many developing countries, a total phase out of MB (except essential use) could be within reach before or during 2006, well in advance of the agreed Montreal Protocol phase out date of 2015 for developing countries (Sidi Ahmed 2002).

Advancement of the phase out date is mainly due to three major reasons: a) The availability and proven efficacy of the alternatives in developing countries; b) Developing countries want to catch up with developed countries in terms of new technologies; c) Developing countries want to ensure continuity of exports to developed countries who may not accept products treated with MB after the deadline of 2005 (Sidi Ahmed 2002). In Lebanon, 97 % of the MB used for vegetable production has been phased out using soil solarisation, biofumigation, grafting and minimal use of 1,3-D (Hafez *et al.* 2003). In Turkey, MB will be phased out in 2008 by adopting non chemical (solarisation, biofumigation, biological control, soilless culture and chemical (1,3D, metam sodium, dazomet ) alternatives (Ozturk *et al.* 2002).

*Developed countries*

A substantial number of chemical and non-chemical alternatives presently used commercially in developing countries (Table 2), have proved to be as effective as MB for controlling tomato soil borne pathogens in many developed countries such as Belgium (Pauwels 2002), Spain (Bello *et al.* 2002, Tello 2002), Italy (Cartia 2002, Minuto *et al.* 2003a), Greece (Tjamos *et al.* 2002), France (Fritsch 2002). However, in spite of their efficacy, some developed countries have requested the Parties to the Montreal Protocol in 2003 and 2004 to grant Critical Use Exemptions (CUEs) for tomato production (Table 3).

Table 2: Main alternatives to methyl bromide used for tomato production in some developing (MLF demonstration projects) and developed countries

| Alternatives | | Countries |
|---|---|---|
| Non chemical | Biofumigation | Chile China, Guatemala, Lebanon, Macedonia, Morocco, Turkey, Uruguay<br>*France ,Greece, Italy, Portugal, Spain* |
| | Grafting | China, Lebanon, Morocco, Romania, Guatemala<br>*Belgium, France ,Greece, Italy, Portugal, Sp*ain |
| | Solarisation | Argentina, Lebanon, Morocco, Syria, Turkey, Uruguay<br>*France , Greece, Italy, Portugal, Spain*, |
| | Steam | Morocco, Jordan, Lebanon<br>*Belgium, France ,Greece, Italy, Portugal, Spain* |
| | Biological control | Jordan, Lebanon, Turkey<br>*France ,Greece, Italy, Portugal, Spain* |
| | Soil less | Morocco, Turkey<br>*Belgium, France ,Greece, Italy, Portugal, Spain* |
| | Resistant varieties | Worldwide |
| Chemical | Dazomet | Chile, Guatemala, Lebanon, Turkey, Uruguay<br>*France ,Greece, Italy, Portugal, Spain* |
| | 1,3-D | Morocco, Lebanon, Turkey<br>*Belgium, France ,Greece, Italy, Portugal, Spain* |
| | Metam Sodium | Argentina, Guatemala ,Morocco, Turkey, Uruguay<br>*Belgium, France ,Greece, Italy, Portugal, Spain* |
| | Chloropicrin | *Belgium, Greece, Italy, Portugal, Spain* |
| Combination | Chemical x Chemical<br>Chemical x non chemical<br>Non chemical x non chemical | Argentina, Chili, Guatemala, Lebanon, Macedonia, Morocco, Syria, Turkey, Uruguay<br>*Belgium, France ,Greece, Italy, Portugal, Spain* |

*France etc:* Developed countries (references in the text)
Morocco etc..: Developing country (MBTOC 2002)

## CRITICAL USE EXEMPTION AND CONSTRAINTS TO THE METHYL BROMIDE ALTERNATIVES ADOPTION IN DEVELOPED COUNTRIES

*Critical use exemption*

Consumption of MB can be classified as that for Quarantine and Pre-shipment (QPS, currently exempt reduction and phase out) and non-QPS. Under Article 2H of the Montreal protocol, the production and consumption of MB for non-QPS uses is to be phased out in developed countries by 1 January 2005 (Batchelor 2002). However, Decision IX/6 of the Protocol established criteria for determining when an applicant would be eligible for a CUE (TEAP 2003 a,b). There are several criteria but the main ones are that the use of MB should qualify as "critical" only if the nominating party determines that a) the lack of MB for that specific use would result in significant market disruption; and b) there are no technically and economically feasible alternatives or substitutes available to the user that are acceptable from the stand point of environment and health and that are suitable to the crops and circumstances of the nomination.

*Constraints to the Methyl Bromide alternatives adoption*

The nominations presented by some European and non European countries cited several categories of reasons for CUNs (UNEP 2004a and b):

- Absence of identified alternatives: e.g. resistant cultivars and root stocks to a broad spectrum of pathogens and races;
- Lack of approval by regulatory authorities: e.g. chloropicrin is not registered in France but registered in other European countries; the combination of chloropicrin +1,3-D is registered in Spain but not in Italy; lack of availability of the granula formulation (Dazomet); Uncertainty of continued registration of a chemical alternative (Smeets 2004)
- Insufficient time to develop the necessary infrastructure: e.g. commercial nurseries, specialized companies for chemical application (e.g. chloropicrin)
- Lack of training in the use of alternative and adaptation of the process to local conditions: e.g. solarisation, grafting, biofumigation, drip irrigation
- Available alternatives are not suitable for local conditions: e.g. solarisation, breakdown of resistance by high temperature
- Longer time between fumigation and planting (plant back periods) with the use of some alternatives, causing disruption to cropping programmes: e.g. metam sodium, chloropicrin
- Available and suitable alternatives are not economically viable: e.g. propagative materials, steaming, soilless cultivation, electric energy availability at farm level

However, all the nominations have only considered the adoption of single alternative to solve tomato soil borne pathogens problems. MBTOC (2002) reported that alternatives should be considered as components of an IPM program, combining strategies and tactics to prevent or manage pest problems.

In 2003 and 2004, respectively only 5 and 3 countries have requested critical use exemptions for tomato production (Table 3) compared with more than 60 countries (Anon 1999) that have used MB. This reduction of 60% of the countries requesting critical use exemptions in one year demonstrates the availability at a commercial level of efficient alternatives to methyl bromide for tomato production.

Table 3: Critical use nominations by Parties to the Montreal Protocol requesting the use of methyl bromide for vegetable production

| **Crop** | **2003** | | **2004** | |
|---|---|---|---|---|
| | **Tonnage nominated** | **Number of nominations (*)** | **Tonnage nominated** | **Number of nominations(*)** |
| Tomato | 4,312 | 5 | 4,012 | 3 |
| Peppers and eggplants | 2,033 | 9 | 2,948 | 7 |
| Cucurbits | 1,993 | 9 | 1,422 | 8 |

(*): USA included

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**LEADING METHYL BROMIDE ALTERNATIVES FOR TOMATO PRODUCTION IN THE UNITED STATES OF AMERICA**

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**ABSTRACT**

The search for alternatives to methyl bromide (MB) began in 1991 with the evaluation of 1,3-dichloropropene (1,3-D), chloropicrin (PIC), metam sodium (MS) and dazomet for controlling soil-borne pest and disease affecting tomato production. Pebulate for weed control showed promise until it was deregistered. Chloropicrin followed by MS or 1,3-D gave effective control of nutsedge weed. Methyl iodide, sodium azide and dimethyl disulfide are relatively new products that show promise. Polyethylene film (as Virtually Impermeable Film, VIF) applied to the soil allows MB to remain efficacious at rates 25-50% lower than without film. There is greater potential for the use of VIF providing manufacturers can supply to the standards required. The most likely replacement for MB in for US tomato production is 1,3-D+PIC with a herbicide or mixture of herbicides. Funding for research on alternatives has diminished and interest in alternatives is waning because the implementation is protracted. Finding alternatives to MB requires scientists to not only test and develop treatments but also to act as agents of change.

**Keywords**: methyl bromide, alternative, 1,3-dichloropropene, chloropicrin, metam sodium, solarisation, methyl iodide, sodium azide, dimethyl disulfide, Virtually Impermeable Film, tomato

## INTRODUCTION

Few of us like change and vegetable growers are no different. The average USA tomato grower is under 50 years of age and has used methyl bromide (MB) all of their farming life. The farmers use a production system which was developed around MB as a soil fumigant and which allows them to be competitive in today's market. MB provides consistent, efficacious results. The loss of MB is a change the average growers' fears as it is a threat to their financial survival.

While most growers have confidence in research conducted on their behalf, they are much less confident in a future without MB. They see themselves as the risk takers and feel scientists have no real financial stake in future results. Most scientists do research in small plots, not in hectares, and growers will tell you that it is different out there in the "real world". There are many reasons for this philosophy, but the end result is that to provide the greatest benefit to farmers during the transition from MB, scientists not only have to provide solutions but also have to serve as agents of change.

To achieve these goals, we have employed a four step process:

1) Evaluation of efficacy and crop response;
2) Identification of problems related to efficacy or application;
3) Ways to improve efficacy or minimize problems; and
4) Delivery of the information to the grower clientele and engagement of them in the process so technology transfer is successful.

We began our search for alternatives in 1991, working with commercially available products, focusing our efforts on tomato as our model crop due to the size of the tomato industry. We spent a lot of time reinventing the wheel because most of the scientists who had worked with products before MB had retired or died. We evaluated efficacy of products like 1,3-dichloropropene, chloropicrin, metam sodium and dazomet and determined their strengths and weaknesses. Once we identified weaknesses, we began experimenting with combinations of fumigants as well as different application methods to improve performance. The purpose of this paper is to familiarise you with some aspects of this process and the results of research to find alternatives to MB.

## WEED CONTROL

Early on it became clear that the greatest impediment to adoption of any of the existing alternatives was going to be weed control, especially control of purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentus*). None of the alternatives provided consistent control of these weeds and consistency is required for a successful alternative. As a result, we had to broaden our search and integrate the limited selection of herbicides with fumigant alternatives.

Eventually, we determined that the combination of a broadcast, incorporated application of pebulate herbicide followed by injection of a mixture of 1,3-dichloropropene + chloropicrin into the raised soil beds provided the required soilborne pest control under most conditions. Demonstration / research trials were conducted on commercial farms in cooperation with local farmers and results were generally good, but inconsistencies did occur and were usually the result of mistakes made at the grower level in the application and incorporation of pebulate. Unfortunately, pebulate was de-registered in the United States resulting in a renewed search for other weed control chemicals and measures.

## FILMS

Research continued with registered alternatives and experimental products were brought into the research programme, including fumigants and herbicides, but also mulch films and solarization.

Paper mulch film was found to be very effective at reducing nutsedge emergence through the film, but it quickly rotted where the soil covered the edge of the material and wind would blow large sections off of the field. We also began investigating gas impermeable or virtually impermeable mulch films as a means of reducing MB rates and emissions. Early VIF products had very poor handling characteristics and would rip easily during installation. Also, there were differences in fumigant retention as well as amount of UV inhibitor and resultant field life.

Once a film with suitable handling characteristics was identified in small plot trials, larger grower demonstration/ research trials were conducted. Unfortunately, installing mulch film in small research plots is very different from doing it in a commercial situation where time is money and large areas must be treated quickly in order to meet production schedules. Minor handling flaws become major ones in these situations. What we have seen is that there are still differences in handling properties and MB retention among VIF manufacturers and within products from one manufacturer. As a result, growers are very reluctant to adopt VIF.

Despite the practical difficulties of applying film to the soil and the reluctance by growers to use film, there are benefits that are most encouraging to growers: Reduction in emissions and cost savings. Our research shows that MB rates can be reduced to 25% of the standard rate with no loss in efficacy or yield when combined with a good VIF mulch. Grower scale trials have repeatedly demonstrated the success of a 50% reduction in rate with VIF.

While VIF reduces emissions over a given time period, combining the emission reduction potential with greatly reduced rates potentially results in even larger reductions in total emissions during the phase-out period. Preliminary research indicates that VIF mulch has potential with several alternatives, most notably methyl iodide, chloropicrin and 1,3-dichloropropene. Use of VIF mulch in combination with 1,3-dichloropropene + chloropicrin has greatly improved weed control with no decrease in crop yield. Experiments just completed this spring indicate that acceptable nutsedge control can be obtained with this combination.

VIF also has the potential to reduce the quantity of methyl iodide required for a given level of pest control and thus make methyl iodide much more cost competitive, thereby reducing one of the greatest impediments to its adoption by growers.

In order for VIF to be adopted by US growers, handling characteristics need to be improved to the point where film can be laid at speeds of 6 to 8 km/hr without tearing. Also, the film should have sufficient UV inhibitor to last for the required time interval and there has to be consistency from one production lot to another. Manufacturers must maintain very strict quality control procedures to assure acceptance of their product in the U.S. market. Part of the success of VIF in the UK and other portions of Europe is the greater film thickness compared to what is being sold in the US. This provides greater strength and reduces rips and tears which will not be tolerated in the US market.

## ALTERNATIVES TO METHYL BROMIDE

### Soil solarisation

Soil solarization can work under the proper circumstances. We demonstrated good control of nutsedge in some early work with infrared retentive film. To be successful solarization has to be practiced for at least 8 weeks. There is seldom more than 8 weeks between tomato crops in Florida. Thus, there is little time for solarization and the time available is not the best time for effective solarization.

### Metam sodium

Metam sodium (MS) has come a long way since 1991 in terms of efficacy and consistency. Early work focused on application through existing fumigant delivery equipment which utilized chisels spaced 30 cm apart for MB application. Results were poor.

We worked with many different application methods, including more chisels, spraying MS ahead of disk hillers then shaping the finished bed, incorporation with rototiller, disk, or spring tooth harrow, spraying on the bed surface prior to laying the mulch film, subsurface delivery, and delivery through the micro (drip) irrigation system. The failure rate was greater than 3 out of 4 initially.

Today, we achieve much greater consistency, but only by applying MS as a spray just ahead of a rototiller then forming a bed and covering it quickly or application through multiple drip irrigation tubes on the raised bed. We have learned that to be effective, the soil must be moist at the time of application but not too wet, the MS must be delivered uniformly to the soil, the target pest must be actively respiring, the soil temperature must be sufficiently warm but not too warm, and the product must be delivered to the area where the pest is located and the MS must be present in the proper concentration for the correct time duration.

We just completed some concentration experiments, but we still do not know the correct time duration for a given concentration. We do know that MS does not move beyond the wetting front. It only goes where the water goes which is about 20 cm in the upper reaches of the bed in the sandy soils of the southeastern US where most of the fresh market tomatoes are produced. Thus, the number of irrigation tubes required per bed is based on the width of the bed and multiple tubes are not practical or economical in all crops.

### Chloropicrin

Our research has demonstrated that chloropicrin (PIC) can stimulate the emergence of nutsedge if applied at the proper rate and that this stimulation can be used in combination with delayed application of MS to provide greatly improved nutsedge control. This approach can be used with either PIC alone or in combination with another fumigant, such as 1,3-dichloropropene (1,3-D). However, the requirement for multiple micro-irrigation tubes still determines how practical this will be and limits the procedure to certain crops, one of which is tomato, provided the bed is not too wide. Most growers prefer a 1 m - wide bed for a number of reasons, so adoption of this technique will require changes in bed width and the equipment which forms the bed. Again, changes are slow to come.

### 1,3-dichloropropene + chloropicrin

Numerous grower demonstrations were conducted for several years, then the personal protective clothing required for use when applying 1,3-D became more stringent and once again our efforts had to be shifted. In an effort to reduce the impact of these requirements on farmers, research was conducted on the efficacy of 1,3-D + PIC when applied broadcast and not tarped. Early results were poor and inconsistent, so emphasis was placed on identifying the best equipment and technique for broadcast application. The Mirusso - Yetter Avenger coulter applicator was the result of this work and enabled growers to achieve consistent soilborne disease and nematode control with this mixture.

Results with the emulsifiable concentrate formulation of 1,3-D + PIC also have improved as a result of drip irrigation studies. We know that this product moves beyond the wetting front as a gas, so irrigation tubing can be spaced farther apart than with MS. However, it still requires more than one tube for a bed, thus increasing cost and the difficulty of aligning everything properly in order to achieve maximum efficacy and planting precision without damaging the drip tubing.

**New products**

New products are investigated as they become available because we still do not have an alternative with which growers feel completely confident and one alternative is not enough in today's changing regulatory environment.

Methyl iodide or iodomethane appears to be the closest thing to a drop-in replacement for MB. It can be applied with existing application equipment and is a true broad spectrum fumigant. It has shown promise against soilborne fungi, nematodes and weeds, including the nutsedges, but more research is needed to better define rates. Methyl iodide is projected to be rather expensive so a lot of early research was conducted with fairly low rates and various formulated mixtures with chloropicrin in order to be price competitive with MB. This resulted in mixed efficacy reports and mixed opinions as to the effectiveness of methyl iodide as a potential replacement. Lastly, the US-EPA has been slow to register methyl iodide and this delay has not inspired confidence in its potential.

Sodium azide initially was researched as a soil biocide in the late 1960's and early 1970's. While it showed real promise, the manufacturer chose to cease registration activities because of safety concerns associated with the granular formulation and the strong market position of MB at the time. Today sodium azide is again being investigated, only this time it is formulated as a stabilized liquid with the preferred application method being injection through drip irrigation tubing with water as the carrier and diluent. As with MS, it is affected by the lateral distribution of the water carrier in the soil. Rates are still being investigated and concentration appears to be a more appropriate way to express the "rate". Results with tomato have been very promising when applied correctly at the proper concentration.

Dimethyl disulfide (DMDS) is in the early stages of evaluation in tomato in the US. Preliminary results have been somewhat mixed but overall are positive. A very odoriferous compound, DMDS appears to be compatible with application via drip irrigation tubing and standard chisel or knife injection. Rates need to be better defined as well as pest control spectrum and crop response.

## CONCLUSIONS

All of the products discussed have been non-injurious when applied to tomato properly at the correct rate, but teaching growers the finer points of rates and application can be challenging. Few tomato growers have experience with herbicide application to the soil in which the plants grow. Most of their experience is based upon shielded spray applications of nonselective contact herbicides, such as paraquat, to the soil between the polyethylene mulch covered, raised beds. In this situation, errors in calibration, herbicide rate selection, and application procedures generally do not affect the crop. When you begin making applications to the soil in the bed, mistakes can be costly. The learning curve for this aspect of the implementation of alternatives is very steep.

Today, the US tomato industry is most likely to replace MB with 1,3-D + PIC with herbicide or mixtures of herbicides. Some growers will use MS in combination with 1,3-D + PIC. The future is difficult to predict because it involves regulatory considerations as well as efficacy and economics, but we believe there is great potential for VIF, if manufacturers provide what growers want.

The search for viable alternatives has been more difficult than initially considered and there is still much to be done. Funding has greatly diminished and interest is waning as the process is protracted. Not every grower will survive because change comes hard to some, but the ones who become engaged in the search for alternatives and sincerely want to learn will survive if we do our job properly. In this process we are not only scientists but also agents of change and we need to do our best to support our farmers.

# PROTECTED VEGETABLE PRODUCTION IN THE MEDITERRANEAN REGION WITHOUT THE USE OF METHYL BROMIDE

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## ABSTRACT

Greece has significantly reduced methyl bromide (MB) consumption from about 900 tonnes in 1991 to 270 tonnes in 2003. MB has been used mainly for pest control in 3,500 ha of greenhouses that produce tomatoes, cucumbers, strawberries, peppers and melons. In response to the ban by the Greek government on the use of MB sold in disposable cans, a mobile non-MB fumigation system has been commercialised. Six trucks equipped to apply a combination of 1,3-dichloropropene (1,3-D) and chloropicrin (PIC) have the capacity in 2004 to replace 60-80 tonnes of MB used in 150 ha of greenhouses. Applicators and their assistants have been trained in how to use automatic equipment on each truck to safely and efficiently apply these fumigants for pest control. Each truck will operate over a 15-20 km area around their home base. In order to meet demand for this service a further 6 trucks are planned toward the end of 2004. Deployment of the alternative is impeded by lack of water in some areas, lack of PIC registration for some crops, and the requirement for a delay between fumigation and planting of 20-28 days which is about 4-5 times longer than required by MB. The costs of the 1,3-D+PIC is the same as MB fumigation. The widespread adoption of 1,3-D+PIC will help Greece to meet its commitment to end its uses of MB by the use of alternatives.

**Keywords:** 1,3-dichloropropene, chloropicrin, tomatoes, cucumbers, strawberries, peppers, melons, greenhouses, methyl bromide, alternative

## INTRODUCTION

Methyl Bromide (MB) has long been used in Greece as the main fumigant in greenhouses. Greenhouses in Greece occupy an area of 3,500 ha of which 1,500 ha were fumigated with MB annually. With restrictions on its use under the Montreal Protocol going into effect and the gradual reduction of the quantities allowed per country (Table 1), there are a very few alternatives available that can substitute the specific product.

Table 1: Methyl bromide quantities used in Greece

| YEAR | TONNES OF METHYL BROMIDE |
|---|---|
| 1991 | 900 |
| 1999 | 675 |
| 2001 | 450 |
| 2003 | 270 |
| 2005 | 186* |

* Estimate, figure has not been finalised.

In the past MB in disposable cans were used by fumigators (5% of the fumigated area) and farmers (95% of the area) for disinfesting greenhouses. As EC market volumes reduced based on compliance with EC regulations, farmers started using Virtually Impermeable Film (VIF) and reduced quantities of MB at 450 kg per hectare. Farmers applied metam sodium, nematicides or solarization techniques where MB was not used. In many cases the farmers were not satisfied with the results.

The use of MB cans was prohibited on 18 December 2003 by the Greek Government. This prohibition was of great concern to Greek farmers since there had been little preparation to cope with the ban. Only 3 fumigation units had been established over the years to apply MB in cylinders using the hot gas method. Three fumigation units were insufficient to cover the demand that suddenly occurred as a result of prohibition of MB in disposable cans.

In order to overcome these difficulties, ALFA SA registered chloropicrin (PIC) with the Greek Ministry of Agriculture in September 2003 for use in greenhouses. Alfa SA decided on PIC after an extensive review of the pest control literature and international practices, basing its selection on its experience of using MB alternatives in Italy and Spain. Alfa SA developed special automatic machines to allow qualified fumigators to accurately and safely apply PIC.

## 1,3-D+PIC INTRODUCTION TO THE GREEK MARKET

In October of 2003 the first demonstration trials using PIC were carried out with the assistance of SIS Italy. During the period of October of 2003 to May of 2004 the trials were carefully monitored so as to prove the efficacy of the product and its combinations with 1,3-dichloropropene (1,3-D). The results of the trials are shown in Table 2.

Table 2: Results of trials with chloropicrin, and 1,3-dichloropropene + chloropicrin, in greenhouse crops

| Region | Crop/ Acreage | | Target | YIELD TN/HA | VARIETY | OTHER PRODUCTS APPLIED | |
|---|---|---|---|---|---|---|---|
| | | Product Dose -Rate | | | | Name | Date |
| Katerini (N.Greece) | Strawberry/ 300 $m^2$ | TRIPICRIN 300 Kg/Ha | Mainly soil born diseases and some nematodes | 30 (48000plants/ ha) | KAMAROSA | - | - |
| St. George (N.Greece) | Pepper/ 750 $m^2$ | TRIPICRIN 350 Kg/Ha | Nematodes and soil born diseases (mainly Fusarium) | 60 (27000plants/ ha)<br>Yield was reduced by 50% because of Phytopthora reinfestation) | LAMUO | - | - |
| Pyrgos (S.Greece) | Tomato/ 1000 $m^2$ | TRIPICRIN 350 Kg/Ha | Nematodes and soil born diseases (mainly Pyrenochetae) | 200 (25000plants/ ha) | BELLADONA | Acylon Combi (Metalaxyl + Folpet) | 18/11/03 |
| | | | | | | RIDOMIL (Metalaxyl) | 30/12/03 |
| Lakonia (S.Greece) | Eggplant/ 2.500 $m^2$ | TRIPICRIN 350 Kg/Ha | Nematodes and soil born diseases (mainly Fusarium) | 100 (25000plants/ ha) | TSAKONIKI | - | - |
| Tymbaki (Crete) | Tomato/ 1800 $m^2$ | TRIPICRIN (250 Kg/ Ha) +CONDOR (250 Kg/ Ha) | Nematodes soil born diseases (mainly Fusarium) and weeds | 140 (25000plants/ ha) | BELLADONA | Nemacur (Fenamiphos)<br><br>Mirage (Prochloraz) + Benlate (Benomyl) | 16/12/03<br><br>30/1/04 |
| Ierapetra (Crete) | Tomato/ 2750 $m^2$ | TRIPICRIN 30 Kg/Ha | Mainly Fusarium and some nematodes | 200 (16000plants/ ha) | ELECTRA | Terrazole (ehidiazole) | 31/10/03 |
| | | | | | | Nemacur | 5/12/03 |
| | | | | | | Vydate | 16/1/04 |

As the demonstration trials were successful, Alfa SA, SIS Italy and six leading dealers of the Greenhouse Sector introduced the first six pilot fumigation units to apply 1,3-D+PIC. The training of the fumigators, as well as the purchase of the drip application machines and vehicles, was undertaken by Alfa SA.

The application machine with its safety features enables each unit to accurately and safely apply 1,3-D+PIC as the flow rate of the products and water volume were both controlled automatically. 1,3-

D+PIC does not deplete the ozone layer and the method of application makes it safe for both the fumigator and the end user.

Like all new methods, the use of 1,3-D+PIC using the drip machine is not without problems. Compared to MB, 1,3-D+PIC requires a high water volume (about 285m$^3$ per ha) and hence it is time consuming and very costly in places of low water supply. The delay between applying the product and planting is 28 days compared to 5 days with MB. The label needs to be extended to include more crops.

## ECONOMICS OF 1,3-D+PIC COMPARED TO METHYL BROMIDE

Increased standards required by the Greek Ministry of Agriculture, including accuracy of dosage, operator safety as well as time and investment constraints for MB applied by the hot-gas method, have resulted in similar costs per ha for MB and 1,3-D+PIC (Table 3).

Table 3: Economic comparison of 1,3-dichloropropene and chloropicrin combination with methyl bromide

| YEAR | 1,3D / PIC * (€ / ha) | Methyl bromide (€ / ha) |
|---|---|---|
| 2003 | 6000 | 4600 *** |
| 2004 | 6000 | 6000** |

*200 lt Chloropicrin and 200 lt 1.3D
** 500 kg of MB
*** Use of 800 cans/hectare (no longer allowed).

## CONCLUSIONS

PIC offers an ideal replacement for MB for soil fumigation when it is applied in combination with 1,3-D. With an equivalent pricing of the two methods it is believed that the initial aim of 150 hectare for the first year (10% of the fumigation market) will be achieved. Primary results from the first 38 hectares already fumigated have been ideal and are proving to be an excellent lever for the development of the specific method. MB must be kept so as to enable fumigators to cover certain problematic areas that are currently difficult for 1,3-D / PIC.

# USE OF GRAFTED PLANTS AND IPM METHODS FOR THE PRODUCTION OF TOMATOES IN THE MEDITERRANEAN REGION

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**ABSTRACT**

Grafting of tomato is a practice that has been known for a long time, but it is only recently that it has increased significantly as it is a good alternative to methyl bromide which must be phased out for soil disinfestation from 1 January 2005. The rootstocks preferentially used are the interspecific hybrids *Lycopersicum esculentum x L. hirsutum*, which is resistant to a wide range of pathogens: *Fusarium oxysporum f.sp lycopersici; F. oxysporum f.sp radicis-lycopersici; Vertcillium dahliae; Pyrenochaeta lycopersici; Meloidogyne sp.* and "collapse". In France, grafting is widespread (2800 ha), both in soil crops (*Pyrenochaeta*) and soiless culture. In Morocco, (20 million plants grafted in a year) or in Italy (10-12 million plants) grafting is used in soil culture and in Spain (45 million plants) both in soil or substrate, to avoid "collapse". In other countries, like Jordan, this technique is in the introductory stage. Grafting is a viable alternative to MB as it is effective against a range of important pathogens and less expensive than MB fumigation of soil.

**Keywords:** Grafting, IPM, rootstocks, tomatoes, rootstocks, methyl bromide, alternative

## INTRODUCTION

Grafted tomato has been known since the middle of the twentieth century as it allows a great many soil pathogens to be controlled. Moreover, it is a viable alternative to soil disinfection using methyl bromide (MB).

### The Rootstocks

The tomato is compatible with several species within its own family, *Solanaceae*, but habitually it is grafted onto rootstocks that are *Lycopersicum esculentum*, *L.esculentum* x *L.hirsutum*, and *Solanum torvum*.

### Grafting methods

The most commonly used grafting method is "splice grafting" and, more rarely, "cleft grafting" (Lee 2003). In both, the variety is rootless at the moment of grafting, thus it is necessary to strictly control the temperature and relative humidity after the operation to avoid plant dehydration and death before the union with the rootstock. In the "splice grafting" method, the rootstock is usually cut below the cotyledons, to avoid rebudding. If the variety ends up sending out roots, the disease can penetrate the plant and annul the effect of the stock. Grafting is carried out by specialized personnel, in nurseries producing horticultural plants.

### Pathogens

The pathogens that grafting can control are Fusarium oxysporum f. sp.lycopersici (FOL); Fusarium oxysporum f. sp radicis-lycopersici (FORL); Verticillium dahliae; Pyrenochaeta lycopersici; Meloidogyne incognita, M. javanica, M. arenaria; Ralstonia (Pseudomonas) solanacearum; "Collapse" (probably Pep MV + Olpidium)

The resistance to FOL and *Verticillium dahliae* is extremely stable (Tello 2002) and the same in the rootstock as in the resistant varieties. Resistance to gall nematodes *(Meloidogyne spp*) provides effective protection as long the soil temperature does not exceed 27ºC (or 32ºC in some varieties). When it is higher, resistance is inefficient (Messiaen 1995). Resistance to Ralstonia is provided by rootstocks of the genus *Solanum (S. torvum or S. aethiopicum).*

True resistance to "*collapse*" has not been reported. Possibly, the improved behaviour of the grafted plants is because they have a greater sap flow rate than ungrafted plants when they are under "stress" conditions (Escudero *et al.* 2003).

**USE OF GRAFTING IN TOMATO IN THE MEDITERRANEAN REGION**

**France**

Grafted tomato has been known in France for many years. It has mainly been used to prevent "corky-root ", caused by *Pyrenochaeta lycopersici* (Beyries 1974), a serious disease in the greenhouse and one to which tomato varieties have no effective resistance.

When, in trying to avoid soil diseases, a large part of production changed to soilless cultivation, grafting was continued in order to prevent FORL which mainly affects cultivars grown on substrate (Coutadier *et al.* 1985; Mazollier 1999; Fritsch 2002). Rootstocks of the type *L. esculentum x L. hirsutum* are used with a complete range of resistance (FOL 2 strains, FORL, *Verticillium, Pyrenochaeta* and *Meloidogyne spp.).*

In soil cultivation the production costs with grafted plants were lower in 1999 than disinfection using MB.

Table 1: Production costs, in Francs/m2

| Concept | Grafting | Without grafting |
|---|---|---|
| Density plants | 1 pl/m$^2$ | 2 pl/m$^2$ |
| Unit price | 8 Fr/unit | 2.8 Fr/unit |
| Cost of plants | 8.0 Fr | 5.6 Fr |
| MB Disinfection | 0.0 | 4.2 |
| Bedding | 0.5 | 0.0 |
| Lettuce treatment | 0.5 | 0.0 |
| **Total cost** | **9.0** | **9.8** |

Mazollier 1999

Annually in France, around 2,800 ha (30% of the total area) are planted with grafted tomato (*Pers comm*. P. Erard 2004). In the tropical countries of French territory, where vascular bacteriosis occurs that is caused by *Ralstonia solanacearum,* it has been a serious problem, grafting has been recommended onto *Solanun torvum* or *S. integrifollium* in order to prevent it (Ginoux 1974; 1996).

**Italy**

In Italy, the most important pathogens affecting tomato are: "corky-root" (*Pyrenochaeta lycopersic*i), FORL and *Meloidogyne spp*. (Cartia, G. 2002). Annually around 10-12 million plants are grafted, the majority in soil cultivation, but grafted plants are also starting to be used in soiless cultivation (Amadio, A. 2004). The rootstocks that are used are of the genus *Lycopersicum esculentum* or hybrids *L.esculentum x L. hirsutum* (Romano & Paratore 2001; Cartia 2002; *Pers comm.* A. Amadio 2004)

**Greece**

The most important pathogens affecting the tomato in Greece are *Pyrenochaeta lycopersici,* FORL, FOL, *Phytophtora, Meloidogyne* spp and *Clavibacter michiganensis subsp. michiganensis* (Tjamos. 2002; Tjamos *et al.* 2002). Solarization combined with grafting is considered to be a good alternative to the use of MB.

**Jordan**

The tomato graft was introduced by the “MB Phase Out Project” in 2002. In that year 1 ha of grafted tomato was planted. This technique is still at the beginning, although it is already being used. To carry out grafting a semi-automatic machine is used to increase labour efficiency. The cost of the grafted plant is \$0.25 - 0.35 per plant, plus the price of the seed (Pers. comm.. MF Al Zubi 2004)

**Morocco**

Genetic resistance and grafting, together with solarization, steam, crop rotation, bio-fumigation and the use of chemical products (chloropicrin, 1,3-dichloropropene, metam sodium), are all considered viable alternatives to MB, in order to control soil diseases that affect the tomato. Grafting prevents FOL, FORL, “Corky-root” and nematodes (Besri 2002; Pers.comm. M. Besri).

At present 20 million tomato plants are grafted, covering a surface of 2000 ha equivalent to 50% of the total plantations for export. Besides the control of soil pathogens, grafting gives greater strength to the plants which allows planting density to be reduced by half (10,000 plants instead of the 20,000 plants/ha). This means the cost of the plants is reduced. Better growth at low temperatures and a longer production cycle are also achieved through grafting. It is expected that within 2 to 3 years time the whole production for export will be obtained using grafted plants (Pers. Comm.. M. Besri 2004).

The bacteriosis caused by *Ralstonia solanacearum* that has been detected in Morocco can be avoided by means of grafting onto *Solanum aethiopicum* or *S. torvum*. The latter is also resistant to *Meloidogyne, Fusarium solani* and *Verticillium dahliae* (Messiaen *et al.* 1995).

**Spain**

Use of MB has never been widespread in tomato cultivation in Spain. This has been possible due to 1) The stability of resistance genes to FOL, *Verticillium* and *Meloidogyne* over the last 20 years; 2) Crop handling (sand-covered soil); and 3) The use of other disinfectants (metam sodium and 1,3-dichloropropene) (Tello 2002).

Contrary to other countries, “corky root” has never represented a serious soil problem in greenhouse tomato cultivation in Spain. Neither has FORL had special incidence, up to now, in cultivation on substrate. Therefore, there has not been any special motivation for grafting with the varieties that usually afforded resistance to FOL, *Verticillium* and nematodes. Formerly, grafting was only practised on non-resistant varieties with special commercial value. (Miguel, A 2002)

The situation changed radically at the end of the 1990s, when "*collapse*" appeared, an alteration which seem to involve Pep MV and *Olpidium* (Lacasa & Guerrero 2002). The disease produces chlorosis at the edge of the leaves, wilting of the buds, death of the roots and, later on, death of the whole plant. It affects both the plants that are in the soil and those that are cultivated on substrates.

In the 1999-2000 the losses caused by "*collapse*" exceeded €9 million as there were almost 1500 ha of tomato grown with more than 50% of the plants affected (Contreras *et al.* 2003). Grafting on rootstocks of the type *L. esculentum x L. hirsutum* allowed the plants to survive and continue producing, while those that are not grafted wither and die (Lacasa & Guerrero 2002).

The number of plants grafted annually in Spain has increased in 4-5 years from less than one million to the 45 million plants at present (*Pers. Comm.* P. Hoyos 2004). This assumes that at least 2,800 ha of greenhouse tomato (most grown on substrate) are grafted plants, all of them produced on nurseries where year after year tomato is the only crop.

In other farms, where the greenhouse tomato is grown in rotation with pepper, melon, watermelon and bean, "*collapse*" never happened. Periodic disinfection is carried out but, since the watermelon is grafted, MB is hardly ever used - instead metam sodium and 1,3-dichloropropene are employed.

The cost of cultivating the long production-cycle tomato in the greenhouse:

| Concept | €/m2 |
|---|---|
| Plastic and greenhouse preparation | 0.451 |
| Ground plastic + substrate | 0.183 |
| Plants (grafted)1.5/m2 | 0.810 |
| Bumblebees | 0.228 |
| Staking twine | 0.210 |
| Fertilizers | 0.549 |

| Concept | €/m2 |
|---|---|
| Phytosanitary products | 0.317 |
| Fuel | 0.216 |
| Water (0.09E/m3) | 0.062 |
| Maintenance watering system | 0.096 |
| Miscellaneous | 0.099 |
| Labour (0.99 hr/m2) | 5.940 |
| Technical advice + administration + repayment | 0.845 |
| **TOTAL** | **10.006** |

Adapted from Berenguer *et al.* 2003; Caballero 2002.

The cost per plant with grafting: 1.5 pl/m$^2$ at €0.54/pl = €0.810/m$^2$
The cost per plant without grafting: 2.5 pl/m$^2$ at €0.18/pl = €0.450/m$^2$

The plant does not represent more than 4.7% (without grafting) or 8.0% (grafted) of the total growing cost. The extra cost can represent the difference between finishing the cycle or to have only half of the harvest period. The additional cost of the grafted plant, €0.360/m$^2$ is always less than that of treating the soil with MB (€0.60/m$^2$ minimum).

## CONDITIONS OF USING GRAFTS AND OTHER TECHNIQUES AS AN ALTERNATIVE TO METHYL BROMIDE

In varieties without resistance, if crop rotation is not practiced, either grafting should be used or soil disinfection periodically (solarization + bio-fumigation; solarization + metam sodium; metam sodium; 1,3-dichloropropene).

When, as is common, varieties with resistance to FOL (2 strains) and *Verticillium* are cultivated, neither of these diseases pose any problem. Although resistances are extremely stable, it is advisable to practice rotation with cultivars that are not sensitive to *Verticillium* or to disinfect the soil from time to time. Similarly for nematode (*Meloidogyne spp*) control. However, when the soil temperature is high, it is necessary to disinfect before planting (solarization + bio-fumigation or 1,3-dichloropropene). Even under normal temperature conditions, when cultivation of tomatoes with gene Mi is repeated, it is necessary to resort to some means of reducing the population to avoid aggressive strains of the pathogen from being selected.

In cold greenhouses, where "corky-root" is a serious problem, the grafting on interspecific hybrid rootstocks *L. esculentum x L. hirsutum*, is an excellent alternative, as effective as MB and cheaper.

In cultivation on substrate, if the variety is not resistant to FORL and if this disease poses a problem, grafting onto rootstocks with resistance is the most logical solution.

Against "*collapse*", both in soil cultivation and on substrate, the only well-known solution is grafting onto very vigorous rootstocks, of the type *L. esculentum x L. hirsutum*, as well as following crop handling procedures that avoid dispersion, through mechanical transmission, of the disease.

## ACKNOWLEDGMENTS

The author thanks the special collaboration of Mr. Al-Zubi M.F (Jordan), Mr. Amadio, A. (Italy), Mr. Besri, M. (Morocco), Mrs. Erard, P. and Mr. Fritsch, J. (France) and Mr. Hoyos, P. (Spain), for their valuable help.

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# THE USE OF FUMIGANTS AND GRAFTED PLANTS AS ALTERNATIVES TO METHYL BROMIDE FOR THE PRODUCTION OF TOMATOES AND VEGETABLES IN ITALY

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## ABSTRACT

Methyl bromide (MB) has been the product of choice in Italy which has been Europe's largest consumer. More recently, some of the uses of MB have been replaced by grafted plants, soilless cultivation, and separate applications of 1,3-dichloropropene (1,3-D) and chloropicrin (PIC). At least 5 ha of greenhouses in the south of Sicily produce 70 million seedlings per year. The plants are grafted onto resistant rootstock that are resistant and/or tolerant to fungal diseases and in some cases nematodes. Melons, watermelons, tomatoes and eggplant are produced from grafted plants. Grafting significantly reduces the use of MB. Soilless cultivation has provided the solution for producing out-of-season, high-quality tomatoes. Expansion of this production system is constrained by the costs of modernising greenhouses and the lack of locally-available expertise. Viable chemical alternatives to MB include 1, 3-D and PIC. Both have been registered in Italy for separate applications since July 2002. Today, 45% of the area once fumigated with MB is now treated with 1, 3-D and PIC and covered with Virtually Impermeable Film (VIF). Specialised machinery is used to safely and effectively apply the fumigants and VIF. Compared to MB, weeds are not always effectively controlled, the lower winter temperatures reduce efficacy, and plant back time is delayed. Farmers are also entrenched in the use of MB and reluctant to use VIF. Despite these limitations, the alternatives to MB are becoming more widely used.

**Keywords**: 1,3-dichloropropene, chloropicrin, soilless cultivation, grafted plants, methyl bromide, alternatives, resistant rootstock, nematode, melon, watermelon, tomato, eggplant

## INTRODUCTION

SIS S.p.A. is the largest Italian company working in the field of soil fumigation. For several decades methyl bromide (MB) was the product of choice in agriculture for assuring the broadest coverage against fungi, nematodes and weeds. Italy has been Europe's largest consumer of MB.

SIS spa provides Italian farms with professional services in soil fumigation:

- Through a network of technical assistance provided by 40 qualified agronomists in every part of Italy;
- With actual licensed, specialised personnel working in teams on the ground;
- With specialized machines/equipment, manufactured within the company

Following a series of decisions taken at an international level in the mid-1990's restricting the future use of MB, SIS has focused on the research for viable alternatives by:

4. Experimentation and production of grafted plants;
5. Experimentation and production in soilless cultivation;
6. Experimentation and subsequent introduction of chemical solutions compatible with the objectives of greater environmental protection.

## GRAFTED PLANTS

Centro Seia, owned by SIS, is a nursery for seedling production. Modern, situated in the south of Sicily, Centro Seia covers more than 5 hectares of greenhouses and produces about 70 million plants per year, distributed all over Italy and certain European countries.

Every year millions of plants are grafted onto rootstock resistant and/or tolerant to fungal disease and, in some cases, to nematodes. These methods are proving to be very effective and the use of such plants is expanding, especially among the more qualified growers.

Nearly all our watermelons are grafted, as are a great number of the melons. For some years now there has been a steady rise in the demand for grafted tomatoes and, in the last two years, a veritable explosion in demand for eggplant.

Grafting significantly reduces the use of MB and guarantees to farmers optimal performance in terms of consistency in quality, conformity in size and resistance to cold in winter.

## SOILLESS CULTIVATION

SIS has dedicated a sector of its business to the production of a flavoursome tomato in soilless cultivation. Six hectares of land have been set aside as a model for this method of growing. The result is a high quality fruit which permits us to supply some of the most important European distribution chains during the autumn-winter-spring period.

This same model is now being emulated by some of the more innovative growers. However, this very same experiment on our part has exposed precisely the difficulties involved in transferring this method of production into the Mediterranean agricultural context. The causes of these are to be found in the costs involved in the modernisation of greenhouses and in the lack of technical expertise in soilless cultivation which is not yet readily available in Italy.

## VIABLE CHEMICAL ALTERNATIVES

For some years now SIS spa has been collaborating with some of the main international companies engaged in the research of substitutes for MB. In particular we have lent our support in conducting the efficacy trials necessary for the registration of new fumigants.

- November 2001: Registration of TELONE EC, nematocide fumigant, the only formulation in Italy based on 1,3-dichloropropene (1,3-D) which is authorised for use in greenhouses (Dow AgroSciences B.V.);

- July 2002: Registration of TRIPICRIN, based on chloropicrin, fumigant with fungicidal and herbicidal action (Triagriberia S.L.)

Since 2002 SIS spa has been committed to converting land that has been treated with MB to treatment with 1,3-D and PIC

| Year | % Converted areas | No. of growers involved | No. of applications |
|---|---|---|---|
| 2002 | 5% | 200 | 465 |
| 2003 | 36% | 1,534 | 2,931 |
| 2004 (August, estimate) | 45% | 2,000 | 4,000 |

Both 1,3-D and PIC are applied with the aid of machinery specially designed by SIS and in cooperation with company's specialised dosage system.

In open fields, SIS spa uses tractors that inject fumigants separately into the deep layers of the soil while simultaneously laying out sheets of virtually impermeable films (VIF), using a method which seals the edges of the films together, thereby blocking the escape of gaseous emissions into the atmosphere.

Inside the greenhouses on the other hand, the products are applied in water through the pipes of the irrigation systems. They are emulsified in water and dispensed, again separately, on ground previously covered with VIF.

Our specially designed machines deliver specific amounts of water together with the correct proportions of the products. Electronic devices continually check that the amount of water delivered, water pressure, concentration and dosages of fumigants fall within set parameters.

As we have noted in both of the systems above, the products are measured and delivered separately. The clear advantage of this, compared with systems of mixing products together, is that it allows for greater flexibility in addressing the particular needs of any given soil, in relation to the type and the degree of infestation.

The growing satisfaction of our customers, together with significant quantitative results achieved in the first two years of commercial use of 1,3-D and PIC, indicates that the traditional usage of MB can be viably substituted in the majority of cases. In addition, the cost of the new products competes favourably with that of MB.

Some limitations of 1,3-D and PIC have been noted and can be summarised as follows:

- Weed control in open fields is not always as effective as it is with MB;
- The use of 1,3-D and PIC may be less effective in winter months due to lower temperatures of the ground.
- Plant back time, which is the interval between application of the products and planting, is much longer than MB and causes delays in some sectors;
- Considerable problems have surfaced with farmers who are fixed in their habits with regard to the use of MB. This means that the work of our agronomists and our specialised licensed workers is imperative, not only in educating farmers in ground preparation and so on, but also in checking the efficiency of irrigation systems,
- There remains some resistance by farmers to the use of VIF, notwithstanding the reasonably contained price of the product.

Without denying the limitations outlined above, the reality is that the substitution of MB is nevertheless in motion and with overall positive results.

It should be added that the fact that PIC can only be given by licensed, specialized personnel means that the product can be traced thereby increasing the guarantees with respect to storage, transport and application.

## COLLABORATION

Of particular value for SIS has been the collaboration it has forged with various universities and research centres. Work carried out with the Universities of Torino, Portici, Piacenza, Pisa, Davis (CA, USA), and with CNR of Bari, has allowed us to deepen our fundamental knowledge on the subject and to perfect soil fumigation techniques in our continued struggle against soil parasites.

Finally, SIS spa actively collaborates with industrial companies with the view to registering new products based on dimethyl disulphide (DSDS, Atofina), Iodomethan (Arvesta), a combination of MB and PIC (DSBG), a combination of 1,3-D and PIC (Dow Agro Sciences).

# ADOPTION OF METHYL BROMIDE ALTERNATIVES IN TOMATO AND VEGETABLE PRODUCTION IN SARDINIA

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## ABSTRACT

In Italy, Sardinia was first region to search for and to find alternatives to methyl bromide (MB) for use in the production of greenhouse crops. Since 1984-85, several trials have been carried out on the adaptation of soilless cultures to the Mediterranean environment, subsequently leading to an important increase in the use of soilless cultivation in Italy. In 1995, Sardinia was the largest region in Italy for cultivated tomato production using low-cost substrates. The introduction of pathogen-tolerant hybrids and of grafting resulted in a partial return to traditional cultivation systems. Over the years, significant changes have occurred at the farm level in the selection of tomato varieties and applied agronomic techniques. Limitations on MB use have stimulated technical and scientific progress in the entire field. The paper reports on the most important changes that have taken place in Sardinia.

**Keywords:** Methyl bromide, fumigation, alternative, grafting, resistant rootstock, tomato, Sardinia

## INTRODUCTION

Since the late 1960's, methyl bromide (MB) has certainly played a major role in Sardinian greenhouse horticultural development. Tomato monoculture and the increased presence of highly virulent telluric pathogens rendered its use essential, initially on greenhouse horticultural crops and then subsequently, although to a lesser degree, on open field vegetables cropped intensively. The knowledge that MB would be strictly limited or even banned stimulated the search for alternatives. The implementation of these alternatives has contributed significantly to changes that have taken place in horticultural production in Sardinia in the last decade.

Examining the trends in greenhouse crop production area in Sardinia over the last 50 years (Leoni *et al.* 2003), (Figure 1), the tomato growing area has markedly increased until 1980. In 1955, tomatoes were produced in greenhouses with only 4% of the production area. Greenhouse production expanded to 50% of the area in 1970 and up to 80% in 1980 . With more crops produced efficiently in greenhouses in the following two decades, the greenhouse area for tomato production showed a proportionally decreasing trend to about 62% in 2003 (Figure 2).

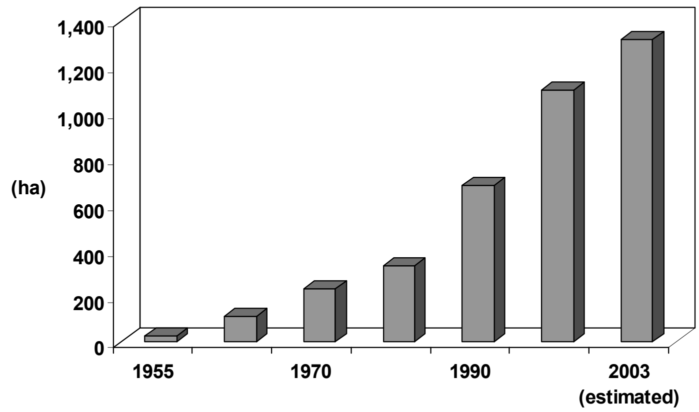



Figure 1: Trends in greenhouse crop production area in Sardinia (1954-2003)

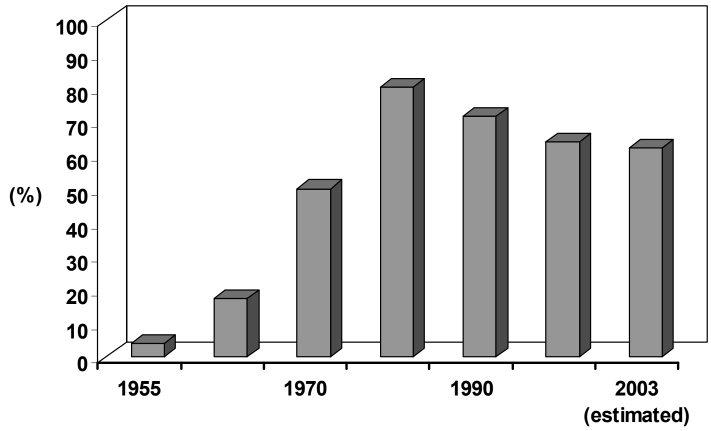



Figure 2: Tomato crop - percentage of total greenhouse area in Sardinia

MB use has increased together with tomato production in both greenhouses and open field production. On the basis of the data provided by the most relevant Sardinian companies in this field, the surfaces annually fumigated reached a maximum in 1992, with around 250 ha in greenhouse and 15 ha in open field. In 1992 the greenhouse surface area was around 600 ha consisting of 500 ha for tomato production and 100 ha for melon and watermelon production.

In Italy, Sardinia has been one of the first regions to carry out an intense research activity establish and to promote new cultivation techniques suited to the Sardinian environment and capable of reducing the use of MB in greenhouses. They were also stimulated by the results of a long term research to monitor brome residues on tomatoes produced in fumigated greenhouses (Leoni and Cabras 1980).

## RESEARCH ON ALTERNATIVES TO METHYL BROMIDE

### Soilless cultivation

Research and trials on soilless cultures started in the mid 1980's and the results subsequently affected greenhouse production of crops both in Sardinia and in other Italian regions. The aim was to adapt the cultivation techniques established widely in Northern Europe to the climatic conditions, technical requirements and economic constraints typical of Southern Italy. It was therefore necessary to highlight the technical problems caused by the Mediterranean climate; to adapt the techniques to the environment and farm type; to simplify pest control activities; to minimise planting and management costs; and to develop alternative equipment allowing the adoption of the soilless culture techniques by less economically favoured farms.

The research itself focused on:

a) Verifying the climatic parameters and their influence on the techniques;
b) Developing economic and easily available equipment;
c) Identifying and studying alternative low cost substrates;
d) Preparing nutritive solutions and defining distribution times and volumes;
e) Evaluating the potentials of these new cultivation systems; and
f) Providing free technical assistance service for preparing nutritive solutions

The most important research and experimental results (Leoni *et al.*, 1990, Leoni & Pisanu, 1995, Leoni, 2003) were:

1. Equipment simplification:

- Use of venturimeters or other low cost equipments for solution dosage;
- Automation of the device for dosing the nutritive solution by using the same control unit, distributor and pipes already employed in greenhouse crops;

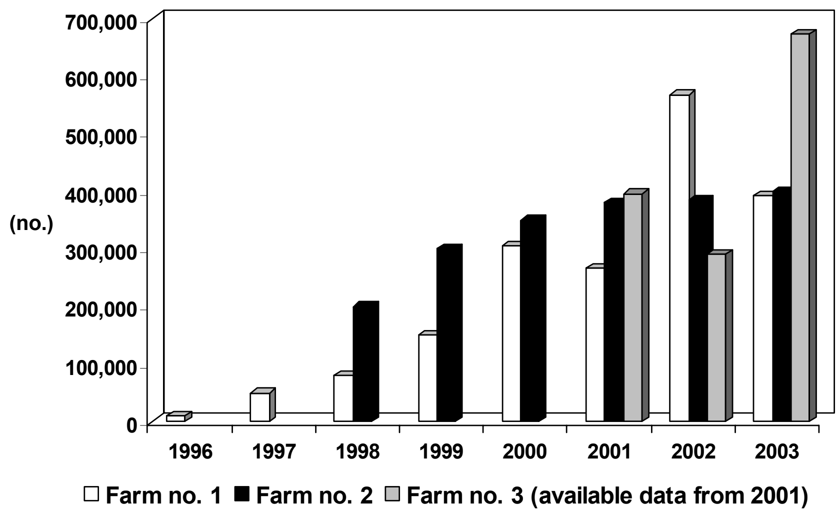
2. Substrate selection:
   - Use of distillery marc, sea straw (*Posidonia oceanica* L. Delille), volcanic lapillus and perlite, as alternatives to the more expensive imported substrate.
3. Preparation and the solution distribution:
   - Understanding of the relationship between elements, salt concentrations, irrigation time, volumes and leaching volumes in greenhouses with no or minimal heating;
4. Choice of cultivation system:
   - The open cycle, Nutrient Film Technique and high-density aeroponic cultivation systems calibration for the Mediterranean environment.
5. Establishment of a free farm assistance, water analysis and nutritive solution preparation service.

As a result of this work, and due to an increase in *Fusarium Oxisporum* var. *radicis lycopercici* attacks in traditionally cultivated crops, soilless culture quickly spread to several farms. Soilless culture area increased from 3.000 $m^2$ in 1989 to around 35 ha in 1993, to reach around 90 ha a few years later. Sardinia became the largest region in Italy for extension and importance in the production of soilless tomato. That was the period of maximum expansion of the new cultivation systems in greenhouse. At the time it represented the only viable alternative to MB fumigation.

**Grafting**

The introduction and spread of grafting occurred in Sardinia from 1996-97. Initially it concerned melon and watermelon only, and later increasingly tomato. Figure n. 3 shows the expansion of grafting by examination of the three most important specialised farms of the sector operating in Sardinia.

Figure 3: Production on resistant rootstock sold by the three most important specialized farms of the tomato soilless production sector




Farms No. 1 and No. 2 produced 80% melon / watermelon and 20% tomato, while Farm No. 3 produced only tomato. The graph highlights an important expansion of grafting of tomatoes on resistant rootstock that, in 2003, produced over 1,700,000 plants covering around 15% of greenhouse cropped surfaces in Sardinia.

Further development of grafting is highly dependant on consumer preference to different types of tomato. If markets develop toward traditional horticultural products, an expansion of grafting will certainly follow. These cultivars are characterized by the absence of genetic resistances and therefore grafting on resistant rootstock is essential. On the other hand, grafting will decline if consumers turn toward less typical, large-production hybrids. Multi-national seed production companies will have greater interest to invest in search for genetic pathogen resistance in hybrids.

**Tolerant hybrids and solarization**

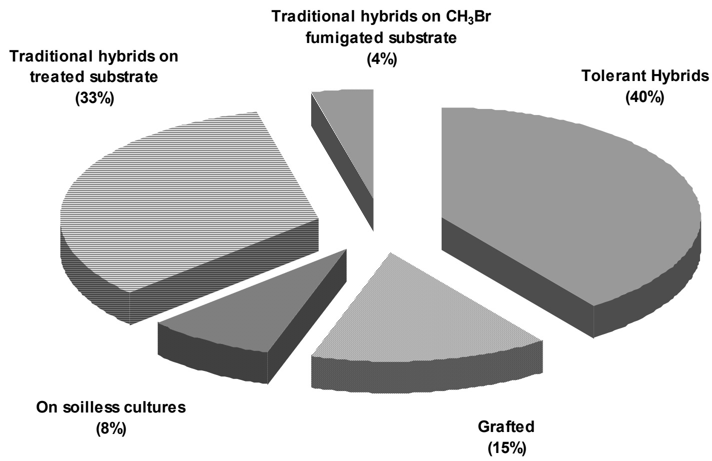
The increasing virulence of pathogens and ineffectiveness of MB fumigation stimulated multinational seed production companies to intensify research efforts to find hybrid varieties with acceptable levels of genetic resistance or tolerance to *Fusarium Oxisporum* var. *radicis lycopercici*.

Since 1995-96, farmers have planted these new hybrids, where possible, as an alternative to those traditionally cultivated. The farmers' choice was favoured by consumers demanding new products. The cultivation of new hybrids and new product types increased: along with traditional "Caramba" and "Camone", such as "Durinta" cherry, "St. Marzano" and the "Beef" types. More recently "Concita" and small "St. Marzano" type have been grown.

The significant change in the selection of the variety was facilitated by solarisation which reduced telluric pathogens that attacked the new hybrids as they had lower levels of tolerance to the most aggressive pathogens.

Varietal diversification brought significant changes both at the farm level, with the adoption of new agronomic techniques, and at the commercial level regarding screening and product packaging. In the absence of precise statistical data, a good summary of current tomato production practices is summarised in Figure 4.

Figure 4: Greenhouse horticulture in Sardinia (2004, estimated data)




In order to give elements for the substrate choice, plant and substrate average costs in Sardinia are reported in Table 1.

**Table 1- Average costs in Sardinia (Italy)**

| Type | Costs (Euros) |
|---|---|
| $CH_3Br$ fumigation, per $m^2$ | 0.67-0.70 |
| Grafted tomato, per plant | 0.77-0.85 |
| Grafted melon, per plant | 0.77-0.80 |
| Distillery marc, in long life p.e. bags (40l) | 1.8 |
| *Posidonia oceanica* L, in long life p.e. bags (40l) | 2.0 |
| Volcanic lapillus, , in long life p.e. bags (40l) | 2.2 |
| Perlite, in long life p.e. bags (32 l) | 3.3 |

## PROBLEMS AND FUTURE PERSPECTIVES

MB use has decreased from 50% of the tomato production area treated in 1992 to just 4% today. The innovative techniques adopted during the last 5 years have reduced the problems related to the presence of telluric pathogens in greenhouse but have not solved all of the problems. Remaining challenges are:

a) The employment of rootstocks and hybrids resistant to *Fusarium Oxisporum* var. *radicis lycopercici*, Resistance to this pathogen has weakened considerably by elevated pathogen infestations in the substrate or by relevant nematode attacks.

b) An increase in *Corynebacterium Michiganense* J. attacks which was recently observed, such as an increase in the frequency of *Pyrenocheta licopersici* S., pathogens to which the hybrids and the most common root stocks do not seem to be particularly resistant.

c) The high costs of grafted seedlings, higher than to those sustainable for soilless cultivation.

d) The re-emergence of such pathogens and the planting over vast areas of the cultivar “Beef” has resulted in a renewed interest towards the adoption of soilless cultivation techniques. In fact, tomato is has recently been more widely grown on *Posidonia* and perlite.

A limit to the large scale adoption of soilless culture is the result of unjustified and absurd resistance of the big food distribution companies toward soilless production. However, the greatest problem presently affecting tomato production in Sardinia is represented by the extreme virulence and spread of TYLCV virus. In some southern areas of the island the virus currently represents a real threat to crop survival.

Grafting as an alternative to MB use is essential for long term monoculture production and especially when *Fusarium* attacks are evident. Unfortunately, *Corynebacterium michiganense* J. and *Pyrenocheta licopersici* S. also attack grafted plants. Sterilising the substrate is essential prior to cultivation. In this respect, cultivation on *Posidonia* is greatly expanding in Sardinia. Promising results have also been obtained on distillery marc and volcanic lapillus.

## CONCLUSIONS

The 1960's expansion of tomato monoculture combined with an increase in highly virulent pathogens in more intensive cultivation areas stimulated, in Sardinia as in other areas of the country, MB use on vast areas. The limitations on the use of MB in the future have contributed significantly to changes in pathogen control and tomato production. The problems that have emerged in this field have stimulated research. The results of this research have totally modified greenhouse horticulture in Sardinia. The ability to adapt to changing cultivation conditions and market demand represents an extremely positive and encouraging aspect for the future of the sector.

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## ALTERNATIVES TO METHYL BROMIDE FOR SOIL TREATMENT IN LATIN AMERICA.

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### ABSTRACT

Latin America accounts for approximately 13% of the current global methyl bromide (MB) consumption, mainly for soil treatment prior to the sowing or plantation of export products such as tobacco, strawberries, flowers, cucurbitaceous, tomato, pepper and others. Alternatives to MB have been evaluated such as biofumigation, solarization, steam sterilization, biological control, graft, crop rotations, soil preparation, soilless crops, chemicals pesticides (Dazomet, metam sodium, 1,3-dicloropropene + chloropicrin) and others. Some of them used alone are able to compete successfully with MB, but for sustainability it will be necessary to integrate all the elements of the crop management to control soilborne pathogens and disease. Some South American countries have substantially reduced their consumption of MB such as Cuba, Brazil and Argentina using alternatives that are technically and economically feasible.

### INTRODUCTION

The main consumption of methyl bromide (MB) in Latin America is for soil treatments prior to sowing or planting exported products of high value such as tobacco, strawberries, flowers, cucurbitaceous, tomato and pepper.

Latin America, as developing countries committed to the Montreal Protocol to eliminate 20% of the consumption of MB in 2005 and 100% in the 2015, is aware of the importance of protecting the atmosphere, the environment and the health of mankind. To this end, efforts are being made to accelerate the phase out of MB before 2015. Recently, an International Conference on Alternative to MB was held in Havana, Cuba. A critical analysis progress was undertaken and actions were approved to promote a reduction and end to MB consumption. In order to achieve this goal, the actions of the implementing agencies of the Montreal Protocol are needed, as well as actions by national politicians and scientific institutions. The development, transfer and adaptation of alternatives to MB will all be necessary to achieve the phase out of MB in Latin American countries.

### CONSUMPTION OF METHYL BROMIDE IN SOIL TREATMENT OF LATIN AMERICA COUNTRIES

Latin America consumes approximately 13% of the current global methyl bromide (MB) consumption. The 2002 consumption was 5,528 tonnes for soil treatment. In the period 2000-2002 a very marked tendency has been shown to complete the international commitments when reducing at global level the consumptions in a quick way, through projects of the Montreal Protocol and others. The main consumers of MB in Latin America have reached consumption figures between 430-2400 tonnes. In the latest years some countries have reduced substantially
the consumption like the cases of Cuba, Brazil and Argentina:

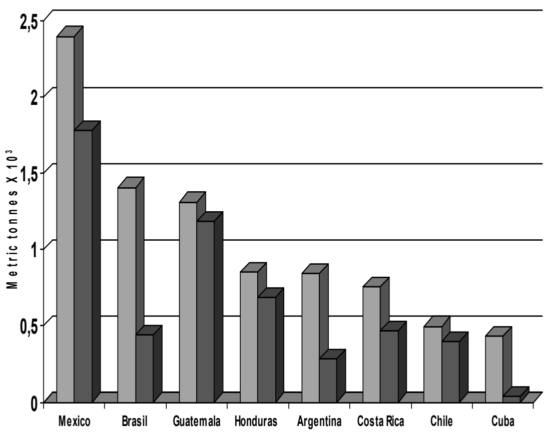


**Figure 1 . The main Latin American consumption of MB and reduction of consumption.**

## MAIN ALTERNATIVES EVALUATED IN LATIN AMERICA AND THEIR INTERACTIONS

For Latin American conditions where the economies vary substantially, being producing with levels of very moderate inputs until those that have resources to develop their productions at the level of the scientific-technical advances, this entail to the development of alternative technologies to MB sustainable to the point of view economic, ecological and social, but mainly it is necessary to dispose of alternative durable and feasible for the great majority. They have been evaluated with success different methods, some of them for itself they are able to compete successfully with an application of MB. Nevertheless, the base of the sustainability will be in an integrated focus where all the elements of the crop management settle down in function of taking the levels populations of noxious organisms to the point that interests us.

Many of the alternatives are complementary. Substitution of MB mostly applies to the chemical pesticides. The following section describes some of the alternatives available.

### Biofumigation

Bbiofumigation has focused from several points of view by the light of the action of the alelochemicals taken place in the soil in the process of the organic matter decay. Bello (1997) during long years of research has showed this alternative with the use of rest of harvest, agro industrial residue, manure or any source of organic matter. Since some years ago has been argued the effect of these substances taken place in the process of organic matter decay in its action to kill or affect fungi, nematodes, weeds and other soil borne pest.

Under the conditions of Cuba the biofumigation has given results that not yet they convince all the people compared with the use of chemical substitutes of MB. However this technology combine with solarization it is of higher effect and from the technical-economic point of view they together are satisfactory.

### Solarization

In the solarization method, the elevation of the temperature originates physical, chemical and biological changes that spread to improve the growth and development of the plants, for this reason it is considered a method usable since different point of view in a integrate pest management. The solarization method does not also require specialized personnel and it neither contaminate the atmosphere. With solarization have registered positive results in more than 12 species of phytophatogens of soil and it is pointed out that the solarization can improve the effect of certain biological control of pathogens.

The solarization method has been effective in Cuba in soil infested with weeds, nematodes and phytopathogens, with satisfactory results in all the times of exposition evaluated of the infested soil (30, 45 and 60 days) in the months of July-August, There where not being detected *Phytophthora nicotianae* var. nicotianae in the soil, neither the bio test plant were affected, while in the control plot the pathogen was recovered and the plants become sick (Table 1). Comparing the two methods of disinfection of the soil, a smaller cost of the transparent film used in solarization compare with black film used with MB was appreciated.

### Steam sterilization

Pasteurization or steam sterilization of the soil is a process by which pests, diseases and weeds present in the soil at a given time are killed by heat. Steam sterilization involves injecting or otherwise diffusing hot water vapour into the soil with the aid of a boiler and conductors such as metal or hose pipes in order to kill noxious soil-borne organisms. The soil needs to be covered with canvas or a resistant plastic sheet to keep the steam in contact with it. As a general rule, it is recommended to carry out treatment so that the coldest spot in the soil or substrate is held at 90°C for % hr. Many variables influence the success and cost effectiveness of steam, for example the boiler and diffusers used, soil type and structure and soil preparation (Pizano 2002)

With this method help to keep sanitation measurement at high level and additions of compost and beneficial organisms such as *Trichoderma.*

Steam can be used as an alternative to MB for flowers grown commercially, when it is part of an integrated management system that helps maintain diseases and pests at low levels of incidence. This allows for treatment of the first 30 cm of soil to be sufficient for reducing pathogen populations significantly. For example, the carnation wilt fungus *Fusarium oxysporum f.sp. dianthl*) can be controlled at costs comparable to those of fumigants.

Table 1: Solarization in Red Ferralitic soil during July and August against *Phytophthora nicotianae* var. *nicotianae*, *M. incognita* y weeds.

| Time (days | *P. nicotianae* | | | | Infestation of *Meloidogyne* (Degre) | | Weeds | | |
|---|---|---|---|---|---|---|---|---|---|
| | Presence of colony | | Result of biotest | | | | Species | Plant / m$^2$ | |
| | S | T | S | T | S | T | | S | T |
| | | | | | | | *S. halepense* | 1 | 7 |
| 30 | - | + | - | + | 1 | 2 | *P. hysterophorus* | - | 11 |
| | | | | | | | *A. dubius* | 1 | 10 |
| | | | | | | | *S. halepense* | - | 15 |
| 45 | - | + | - | + | 0 | 2 | *P. hysterophorus* | - | 14 |
| | | | | | | | *A. dubius* | - | 18 |
| | | | | | | | *S. halepense* | - | 15 |
| 60 | - | + | - | + | 0 | 2 | *P. hysterophorus* | - | 17 |
| | | | | | | | *A. dubius* | - | 20 |

S : solarization T : control

### Biological control

The biological control will be seen as indispensable complementary method, mainly for the maintenance of low level of incidence of noxious organisms in the soil. There are different results mainly for the main soil fungi and nematodes especially *Meloidogyne* genus, some recent results are pointed out next (Table 2).

Table 2:. Some agent of biological control alternatives to methyl bromide

| Agent of biological control | Noxious organism to control | Crop-country | Effectiveness | Source |
|---|---|---|---|---|
| *Corynebacterium paurometabolum* cepa C-924 | *Meloidogyne incognita* | Protected crops of tomato-Cuba | 76 | Mena *et al.* 2004 |
| *Glomus intraradices, G. mosseae G. manihotis* | *Meloidogyne incognita* | Banana and plantain-Cuba | 85 | Fernández *et al.* 2004 |
| *P. lilacinus* | Nematodos agalladores | Water melón-Mexico | 83 | Farias *et al.* 2004 |
| *Trichoderma* spp | *Pythium spp P. nicotianae* | Tobacco, tomato , pepper, substrate-Cuba | 75-85 | Perez *et al.*l 2004 |
| *G. mosseae* | *P. nicotianae* | Tobacco-Cuba | 80 | Fernandez 2004 |
| *Trichoderma viride* cepa C-66 | *Meloidogyne incognita* | Protected crops of tomato-Cuba | 75-80 | Pérez *et al.* 2004 |
| *Bacillus thuringiensis* cepa LBT-3 | | | | |

**Grafting**

Grafting is as method used of prevention of diseases, in plants that belong to the families of the Solanaceous and Cucurbitaceous. In tomato the graft on different pattern allows to fight efficiently against *Fusarium oxisporum sp. lycopersici, Verticillium dahliae,* nematodes (*Meloidogyne incognita*) and others. In pepper, for the prevention of *Phytophtora capsici* and *Meloidogyne incognita*. The graft combined with solarization or biofumigation; allow the substitution of the disinfections with chemical products. (Miguel A. 2004)

In Cuba different patterns are studying to evaluate their resistance to phytoparasites nematodes of the genus *Meloidogyne* , being identified a pattern of pepper highly resistant which was obtained of the program of genetic improvement and two tomato patterns coming from the enterprise De Ruiter Seeds also showed good result. These selections shows very good compatibility implant-pattern and the percentage of for the climatic conditions of Cuba they reached a 98 and 90% in pepper and tomato, respectively (Hernandez A. 2004).

Newness constitutes the combat of nematodes of *Coffea arabica* L. they were detected in Cuba from 1971 in nursery and plantations. To face the affectations of the nematodes, it was carried out in the 80 decade the technological transfer of the method of hypo cotyledonal grafting. It consists on using a pattern of *Coffea canephora* Pierre and implant of *Coffea arabic* L. to be the first tolerant to the nematodes and of second is obtained a product of better quality for consumption (Caro *et al.* 2004).

**Crop rotation**

The traditional scientific base of the agriculture constitutes the crop rotations, hundred of years the land have survived for the agricultural exploitation from the old civilizations, two examples demonstrate that an appropriate handling of cultivations is in a insubstitutable component to combat the main problems of pest.

The main and more difficult weed that it is combats with MB is *Cyperus rotundus*. The systems of handling of cultivations have a high influence in the composition and population of weed. In Cuba, the intercroping (spring sowing), they highly affect the incidence of *C. rotundus* for a bigger proliferation in the most favourable conditions in humidity and temperature, in general the variable rotations crops lead to the best results, because it doesn't allow them to be appear the conditions that contribute to the increase population of the weed (Pérez *et al.* 1990). For reduce the population of *C. rotundus* are appropriate the fallows and the intercropping with sweet potato and corn.

With the saw and incorporation into the soil of *Stizolobium deeringianum* Bort, eliminates the weeds and in the following plantation of tobacco the use of herbicides decreases in 20%, also the intercropping of *Sorghun vulgare* Pers, diminishes the incidence of *C. rotundus* (Fernández *et al.* 1990). in general the leguminous *Canabalia ensiformis* (L) and *S. deeringianum* has demonstrated to be important species in rotation system, that which are associated to the production of toxins.

The succession in horticultural crops is recommended according to the susceptibility of *Meloidogyne spp.* It is known that tomato, eggplant, lettuce and water melon are very susceptible, cabbage and cauliflower are moderately susceptible and garlic and onion are lightly susceptible. Likewise, the cultivations as peanut, sesame, corn or the resistant variety of sweet potato CEMSA 78-354 can be preceded to the susceptible crops. Good results have been achieved in the elimination of *Meloidogyne* in tobacco with the rotation of peanut, millet, velvet bean, corn and sesame (Fernández *et al.* 1990).

**Soil preparation**

The weed that reproduce by vegetative organs (rhizomes, stolons, tubers, basal bulbs, etc.), require tiller and multiplow to take to the surface the self generating organs during the dry period, with the objective of drying these. With 3-4 tiller passes at the end of the preparation this species decrease substantially. The terms between labours to kill weed reproduction by seeds are linked to the conditions existing for the germination, in which the rains play a main role. Under normal conditions during the rainy period, it is required to have 12-15 days between labours. Those of vegetative reproduction, once the rest of the plants have risen to the surface of the soil, a time should be waited depending on the susceptibility of these organs to the drying and loss of viability, for example in the case of *C. rotundus* is 7-9 days. In the Figure 2 is shown that when the time of preparation is more than 40-75 days, the populations of *C. rotundus* decrease to a very low values. This trend is appreciated in the case with more than 10 days between labours (Pérez *et al.* 1999).

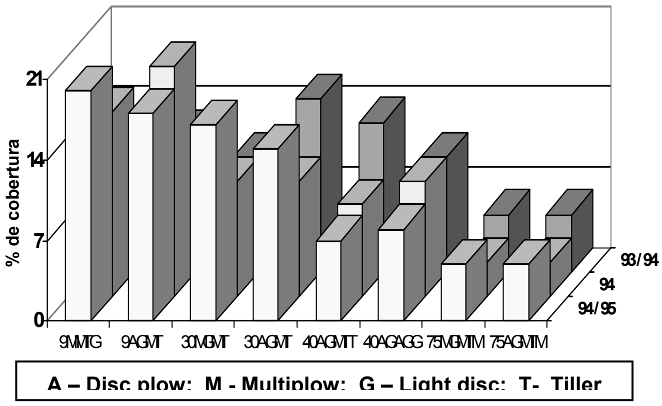


**Figure 2 .Effect of systems of soil preparation against *Cyperus rotundus***

Since the radical systems of several plants or their underground organs, continue live and serving as host to the nematodes, mites and fungus during weeks or months after the crop and to that several species of these parasites have a high survival, still without host, it becomes necessary to expose to the sun effects and the drying of this population of parasites in order to contribute to their gradual decrease. In Cuba, in order to eliminate *Meloidogyne spp*, the use of a disk plow to invert the soil prism and in combination with tiller every 25 days during 80 days (Table 3), has given good results (Fernández 1999).

Table 3:. Effect of the methods of soil preparation against *M. incognita* in tobacco crop in Cuba.

| **Time (days)** | **Reduction of infestation (%) in two dethp of soil (cm)** | |
|---|---|---|
| | **10-20** | **20-30** |
| 50 | 50,21 c | 50,70 c |
| 50 | 46,51 c | 51,42 c |
| 72 | 61,96 b | 58,59 b |
| 82 | 83,68 a | 88,66a |
| 122 | 91,29 a | 89,41 a |
| 142 | 92,34 a | 92,05 a |
| ES= | 3,29 | 4,50 |
| CV(%)= | 10,1 | 9,8 |

## SOILLESS CROPS

### Tobacco

The technology of floating trays with the use of organic substrates provides an alternative of tobacco seedbed productions, of easy handling that are imposing in this agricultural segment, among other reasons, because it is obtains a high number of plants per area of high quality with the protected root.

In Cuba, for the selection of substrates were compared different raw materials as mixture of black pit + husk of rice + zeolite. It was found that the substrate with proportion of 70% + 15% + 15% produces a high quality of the plant compared with the control which it was 80% black pit + 20% husk of rice, with similar percentage of germination and growth (Garcia *et al.* 2004).

The main reached impacts are from the economic point of view, the reduction of 205.6 ha of traditional nurseries, which are useful for other agricultural uses and the reduction in 84% of the necessary areas for the production of same quantity of seedling. The production costs decrease regarding the traditional nurseries in 113.05 US $ for 1 ha plantation, it is represents 17% less.

**Tomato**

The zeolite has been used in Cuba in order to decrease the affectations of nematodes in tomato of greenhouses. The same has been proven during several crops with very positive result. These results are similar to those achieved in crops carried out in soil cultivations. During the cycle of crop was not observed plants affected by nematodes and to the moment of harvest the roots were free of nodules (Cruz and Pérez, 2004).

**Integration of methods**

According to Bello *et al.* (2004), it is necessary to establish model's change for the elimination of MB, based in the ecological theory that allows the self-regulation of the system through the balanced management of the diversity, so much biological as environmental and cultural, trying to design systems of integrated or ecological production, favouring the use of local resources. Model's change will rebound in the bigger farmer's autonomy, at the same time that it will reduce economic expenses unnecessary and serious environmental impacts, giving place to an agrarian production with alimentary, environmental and social high quality. Lastly it is considered that the search of alternative to MB as soil fumigant, it is propitiating model's change in agriculture, especially in the management of the horticultural crops.

In tropical countries the alternative like the use of cultural practices, biological control with the local raw materials, biofumigation and solarization, substrates use with raw materials of national source, they have a high potential of efficiency in interaction with techniques that require high inputs, the level of compatibility among all the available techniques is relatively high (Table 4).

Table 4: Integration of alternative techniques

| | Cultural practices | Biological control | Biofumigation | Solarization | Steam heat | Substrate | Soil amendments & compost | Grafting & resistant varieties |
|---|---|---|---|---|---|---|---|---|
| Biological control | X | | | | | | | |
| Biofumigation | X | X | | | | | | |
| Solarization | X | X | X | | | | | |
| Steam heat | X | X | | | | | | |
| Substrate | X | X | | | | | | |
| Soil amendments and compost | X | X | X | X | | | | |
| Grafting and resistant varieties | X | X | X | X | X | X | X | |
| Chemicals | X | X | X | X | X | X | X | X |

## SUSTAINABLE ALTERNATIVES IN SOME LATIN AMERICAN COUNTRIES.

**Argentina**

Strawberry is an economically important crop in Argentina. Several experiences have been carried out to validate already tested alternatives to MB and to adapt them to local conditions. Dazomet and metam sodium were the fumigants compared for the control of soil-borne fungi, nematodes, insects and weeds. Both products came out as viable alternatives. In addition, two other methods, soil solarization and steam, were also validated. Steam is a quite difficult to apply and the initial overall costs for its application may prevent its use. Some problems related to its application are not easily overcome under current conditions. Soil solarization, although effective under certain conditions, cannot be applied everywhere. The area of La Plata is suitable for the production of strawberry, especially for fresh consumption and in that area all these control technologies can be well applied in strawberry fields.

Tomato is an important horticultural crop in Argentina. Also in this case dazomet and metam sodium were effectively used as soil fumigants. Cropping practices of tomato vary depending on the geographical area, and this may determine the choice of the fumigant, besides the economical feasibility of the treatment.

Carnation and lisianthus, as cut flowers, are the most important ornamentals in Argentina, being cultivated especially in the green belt of Buenos Aires. Dazomet and metam sodium showed the same effectiveness as MB, as mentioned above for strawberry and tomatoes. These fumigants are potential alternatives to replace MB, which is currently used.

For tobacco, the alternatives for the replacement of MB were evaluated in two agricultural systems: (a) the conventional system using chemical fumigants, as metam sodium and dazomet, and (b) the soilless system using floating trays and supported trays. The results showed that both methods may satisfactorily will used in tobacco seedbeds (Salles *et al.* 2001).

**Brazil**

Three validated alternatives to the use of MB for soil fumigation in tobacco were evaluated: Solarization of conventional seedbeds; The use of metam sodium in conventional seedbeds; and the "floating trays" system. Solarization proved to be a technically feasible and cost-effective non-chemical alternative to produce healthy and adequate seedlings. Metam sodium is a very good alternative, too. It is very easy to apply, practically odorless, and it is safer and easier to use than MB. The float production system produces tobacco seedlings for transplant that are of greater uniformity, with a much stronger root system and at reduced labor costs (Salles, 2001 ).

**Cuba**

The technology of the protected crops was introduced in Cuba at the beginning of 1994, with a growing development. The distribution of the technology is mainly given in 4 provinces of the country. The impact of different noxious agents of the soil, such as nematodes, fungi and weed, affect its production for which has been used MB. However, for some years there have been working intensely in the development of viable alternative to MB.

After a process of participative analysis, through workshops, where scientific, specialists, technicians, officials, decision makers and producers participated, they were identified and characterized the most promissory alternatives to be adopted by the producers. As a results of this analysis they are developed to great scale the graft technology, the soilles cultivation, the biofumigation with solarization, the use of rotations crops with cruciferous, as well as the chemical alternatives (Dazomet, 1,3 dicloropropene + chloropicrin) and biological control (*Trichoderma*). Of the mentioned alternatives, the use of *Trichoderma* (Native stream), as well as the dazomet applications are already used with good results. (Muiño & Pérez 2004).

From the environmental point of view, the massive use of the of floating tray technology in tobacco crop has reduced the consumption of water in 91%, the inputs in chemical and biological pesticides and fertilizers in 90% and diesel in 88% (Figure 3).

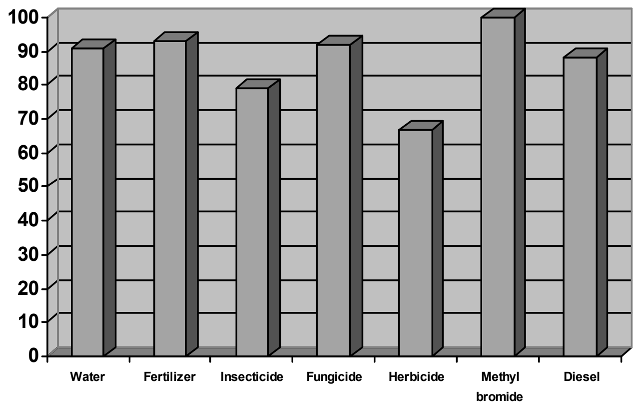


**Figure 3. Reduction of the consumption of agrochemicals, water and diesel with the floating tray soilless technology regarding to the traditional seedbed.**

In a social context it was created a source of employment for women, since a great part of the operations of the technology can easily carry out. It was excludes the MB in the pesticide registration authorized in tobacco (Pérez *et al*. 2004).

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# ALTERNATIVES TO METHYL BROMIDE ADOPTED FOR CUCURBIT PRODUCTION IN PROJECTS FUNDED BY THE MONTREAL PROTOCOL

## MAIN ALTERNATIVES ADOPTED IN PROJECTS FUNDED BY THE MONTREAL PROTOCOL FOR THE PRODUCTION OF TOMATO, PEPPER AND EGGPLANT IN CLIMATES SIMILAR TO THE MEDITERRANEAN REGION

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## ABSTRACT

UNIDO is executing 29 methyl bromide (MB) phase out projects in 25 countries in the horticultural sector. The main crops are melon, watermelon, tomato, cucumber, eggplant and sweet pepper. The alternatives showing the best results in large-scale farming are 1.3-Dicloropropene + chloropicrin, and grafting. Small-scale farmers are trained in replacing MB by the use of grafting, biosolarization or biofumigation, metam sodium and 1.3-Dicloropropene + chloropicrin. UNIDO's goal in implementing alternatives is to maintain production at the same level as when MB is used without increasing the overall cost. UNIDO also aims to adapt the alternatives to the requirements of the producer thus potentially allowing the producer to shift from one alternative to the other depending on the pest-disease complex and the management system.

**Keywords:** grafting, alternatives cost comparison, cucurbits, tomato, pepper, alternatives to methyl bromide.

## INTRODUCTION

UNIDO is one of four agencies that is responsible for implementing 29 methyl bromide (MB) phase out projects in 25 countries. Of all the agencies, UNIDO has the most projects and the largest single budget for the phase out of MB in developing countries. The total budget currently approved is about US$ 42 million. The phase out target is almost 8,200 ODS tonnes.

As developing countries are scheduled to decrease their use of MB by 20% in 2005 under the requirements of the Montreal Protocol, compared to their average base level consumption in 1995-1998, a number of projects have been approved to assist countries to achieve this 20% reduction target. In the near future, further new projects will be implemented to meet the 2005 phase out commitment for MB in developing countries.

Due to the wide range of climatic conditions, farms size, farmer skills and other factors coupled with the constant development of MB alternatives, we have to follow closely farmers' needs to ensure the long-term sustainability of the alternatives proposed.

## CUCURBITS

Melon is the most predominant cucurbit crop in UNIDO`s list of project with watermelon and cucumber being grown in less volume. Melon and watermelon are grown in Central America. Cucumber is grown in the Mediterranean area and Romania.

A typical melon farm covers 1,500 Ha. The farming system is relatively sophisticated with a high level of dependence on MB for soil disinfestation.

The alternatives that have the greatest adoption rates and the confidence of farmers are grafting and 1.3-dicloropropene + chloropicrin (1,3D / PIC). Biosolarization, impermeable mulching film, resistant varieties and new fumigants show potential for the future. UNIDO encourages "good agronomic practices" such as the use of organic matter, water, fertilizer and pest management in order to promote successful control of soil borne pests.

After one year working at commercial scale with grafting and 1,3D / PIC, UNIDO estimates the following costs:

Table 1: Melon seedling, US$ per Ha (Central America)

| SEEDLING COST US$/HA | REGULAR | GRAFTED |
|---|---|---|
| **TOTAL FOR 2 CYCLES** | **$541.93** | **$1,221.12** |
| Number of seedling/Ha, for 2 cycles | 22,000 | 17,600 |
| Seedling unit cost<br>Regular seedling: 242 cell/Tray, 34 x 67 cm<br>Grafted seedling: 128 cell/Tray, 34 x 67 cm | 0.02463 | 0.06938 |

Table 2: Soil treatment: US$ per Ha, melon Central America

| Cost<br>US$/Ha | Methyl bromide<br>+<br>Normal film<br>+<br>Normal seedling | No soil treatment<br>+<br>Grafted seedling | Methyl bromide<br>+<br>VIF<br>+<br>Normal seedling | 1,3-D / PIC<br>+<br>Normal film<br>+<br>Normal seedling | 1,3-D / PIC<br>+<br>VIF<br>+<br>Normal seedling |
|---|---|---|---|---|---|
| **Total** | **$1,648** | **$1,677** | **$1,844** | **$1,948** | **$2,024** |
| **Seedling** | **$542** | **$1,221** | **$542** | **$542** | **$542** |
| **Fumigant** | **$650** | **$0** | **$390** | **$950** | **$570** |
| Dosage Kg/Ha | 250 | 0 | 150 | 250 | 150 |
| US$/Kg | 2.6 | 0.0 | 2.6 | 3.8 | 3.8 |
| **Plastic film** | **$456** | **$456** | **$912** | **$456** | **$912** |
| $m^2$/Ha | 7,600 | 7,600 | 7,600 | 7,600 | 7,600 |
| US$/$m^2$ | $0.06 | $0.06 | $0.12 | $0.06 | $0.12 |

UNIDO has not detected any differences in yield between MB-treated and crops treated with the alternatives, even with considerable effort in this area to measure yield differences. It appears to UNIDO that MB technology has reached its pick of efficiency while other chemicals and grafting have yet to reach their full potential. Grafting requires further effort to establish the best nursery and field management. UNIDO is confident that with further improvements in the use of alternatives to MB it is likely that both yield and fruit quality will increase over time.

In Honduras and Guatemala, in order to achieve the 20% reduction target required of developing countries by the Montreal Protocol by 1 January 2005, UNIDO has installed 60,000 $m^2$ of nurseries for grafted seedling production. At full capacity these nurseries can produce 30 million grafted seedlings per crop season (8 weeks window), equivalent to 3,400 Ha and employs at least 1,000 people. The total melon area in Honduras and Guatemala is about 9,000 Ha. Therefore, our seeding production capacity covers about 30% of the total requirements. We believe that the answer will be a mix of different alternatives,. In developing and implementing a range of alternatives, it will become more important to match the range of alternatives to the crop management system in order to maximise yield and quality.

In the Mediterranean area, grafted melon, watermelon and cucumber are widely used and the demand is constantly growing. UNIDO is implementing several projects in the area. The most advanced project is the one in Romania where grafted cucumber is showing a big potential and is very much appreciated by farmers. Grafting, biosolarization and/or metam sodium and/or Dazomet can control the entire range of soil borne disease and weeds previously controlled by MB. A pilot nursery unit of 1,500 $m^2$ with a capacity of 60,000 seedlings per week will be full operational in October 2004 in Bucharest.

## TOMATO, PEPPER AND EGGPLANT

UNIDO projects involved in the production of tomato, pepper and eggplant concern mostly producers that have small holdings (0.5÷1 Ha). Due to the small land area, MB alternatives can require high-input and intensive crop management. To this end, farmers have recognized the value of biofumigation, biosolarization, grafting and the fumigants metam sodium, and 1,3-D / PIC because they can achieve yield and costs comparable to MB.

UNIDO believes that improving crop management and yield is as important as seeking effective chemical or biological alternatives. In Guatemala, for example, in the course of only one year UNIDO improved soil preparation and crop management practices while at the same time replacing MB with metam sodium. The combination resulted in a doubling of tomato yield. It is difficult to say if the improvement was due to metam sodium or to the new crop management. However, whatever the cause, the farmers remain very happy with the increased production.

Grafting requires a suitable nursery installation to produce high quality grafted seedling. High quality planting material is essential for the success of grafting. In Romania, UNIDO is installing a pilot nursery unit of 1,500 $m^2$ with a capacity of 60,000 seedlings per week. The nursery will produce seedlings for a small group of tomato and cucumber producers. A number of rootstocks are already available, inter-specific tomato for tomato and *Solanum torvum* for eggplant. Both rootstocks have helpful level of resistance and tolerance to the main soil borne pathogens. A tomato variety, resistant to *Xanthomonas* sp., is used in Guatemala as rootstock for a tomato variety with no tolerance. As MB is a weak bactericide it is of no help. In Central America and Mediterranean area, *Solanum torvum* is the common rootstock used for eggplant. It is excellent against nematodes, Fusarium and corky root. Official data will be available in one-year's time.

It terms of cost, it is difficult to generalize from a range of trials as inputs are often not comparable. In addition, labour cost and locally-available natural resources are unlikely to be quantified in developing countries.

## CONCLUSIONS

UNIDO`s experience shows that MB alternatives exist. UNIDO`s effort is focused in two complementary objectives: firstly, providing equipment that is generally unavailable for small-scale as well large-scale farmers; and, secondly, looking at and ways to improve the entire production process.

We have seen that the farmer is willing to invest his own resources in the technology development once the new technology is shown to have potential. This process gives farmers the opportunity to learn new methods and to realise new market opportunities where tight protocols are in force to reduce chemical residues.

When UNIDO approaches a new farmer or a new sector we are unlikely to look just at yield increase. We believe that first we must make sure the alternative can produce the same yield at the same cost. In doing so we can be assured that the alternative is sustainable. If the farmer is able to create a better yield this is an added value that belongs to the skill of the farmer.

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# BIOFUMIGATION AS AN ALTERNATIVE TO METHYL BROMIDE FOR THE PRODUCTION OF TOMATOES AND OTHER VEGETABLES

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## ABSTRACT

Tomato and vegetable crops consume the most methyl bromide (MB) for soil fumigantation corresponds to crops which could be justified for vegetables with long crop cycles. Changes in MB formulation, dose, frequency and method of application are urgently required to reduce consumption. Uncontrolled adoption of chemical and non-chemical alternatives can have serious health and the environment consequences, as foreseen in international commitments such as the Kyoto and Biodiversity Protocols and the Stockholm Agreement. It is necessary therefore to select alternatives based on satisfactory ecological criteria. Biofumigation has effectively controlled soil-borne pathogens and weeds in horticultural crops, increased soil fertility and improved its physical and biological properties. The total cost of biofumigation is less than fumigation with MB even when the costs of plastic film and water are included. Integrated production systems must be designed that give priority to the use of local resources as biofumigants.

**Keywords**: soil-borne, organic matter, soil ecology, crop protection, integrated production.

## INTRODUCTION

The Montreal Protocol has approved 15,615 t of methyl bromide (MB) for soil fumigantion as critical use exemptions (CUEs) for developed countries for the year 2005. Evaluations continue for requests on the use of MB strawberries grown in Israel (196 t) and New Zealand (84 t), peppers in Japan (190 t - 74 t approved = 116 t pending) and cucurbits in France (85 t) for a total of 481 t. For tomato and vegetables, 125 t have been approved for use in France for solanaceous crops which, considering their request for the year 2006, could be divided into 62 t for tomatoes, 31.5 t for eggplant and 31.5 t for pepper. MB for CUEs on vegetables account for 52.4% (8,180 t) of the amount agreed by the Parties for critical uses. Based on the amount of MB recommended for CUEs, 3,960 t are for tomatoes (25.3%), 1,934 for cucurbits (12.4%), and 1,933 t (12.4%) for pepper and eggplant. The rest (353 t) are used for CUEs on other crops such as potatoes in Israel (239 t), sweet potatoes in USA (81 t), lettuce, endive and chicory in Belgium (25 t) and carrots in France (8 t). With the consumption in developing countries, another 6,192 t must be added to this amount, of which 3,096 t (24%) correspond to tomatoes, 2,709 t (21%) to cucurbits, 258 t (3%) to pepper and 129 t to other crops.

An analysis of MB consumption in developed countries shows that Belgium, Israel, Italy, France and USA apply MB for the majority of crops; whereas Australia, Canada, New Zealand, Poland, Portugal and the UK have not requested a CUE for vegetables; Spain applies it only to peppers; and Japan, only for cucurbits and peppers. This would indicate that MB is not essential for vegetable production in temperate climatic countries, where it is only applied in strawberries and cut flowers. It is considered that the use of MB would be justified only when crops are of long duration such as peppers in south eastern Spain. The amount of MB consumed could be reduced through changes in formulation (MB:chloropicrin = 50:50 for controlled environments and 77:33 in the open field), reduced dose (20-30 g/m$^2$), reduced frequency of application (once every two or three years), strip application (10 g/m$^2$) as is done in strawberry fields in Spain.

Some MB alternatives (MBTOC 2002) such as chemical alternatives, solarization and steam may have repercussions on international commitments, such as the Kyoto and Biodiversity Protocols. On the other hand, soilless cultivation may result in the same pollution problems as conventional crops (de Cara *et al.* 2004). As for the use of resistant plants and grafting, if not handled according to an agronomic criterion, virulent pathogen populations may be selected. Therefore, plant protection should be based on ecological approaches. Processes such as the bio-decomposition of organic matter in the soil may have the same function in controlling soil-borne pathogens as chemical fumigants. Biofumigation as therefore an alternative to MB (Bello 1998; Bello *et al.*1996, 2002, 2003).

## BIOFUMIGATION AS AN ALTERNATIVE TO SOIL FUMIGANTS IN VEGETABLES

Our research has permitted biofumigation to be defined as “the action of volatile substances produced during the biodecomposition of organic matter and by soil microorganisms and the roots of some plants for soil-borne pathogen control.” Biofumigation increases in effectiveness over time when it forms part of an integrated production system. It has been found that generally any organic remains with a C/N ratio between 8-20 could act as a biofumigant. Efficacy depends on characteristics, dose and method of application.

### Methods of application

The method must take into account the necessity to retain biofumigant gases produced from the biodecomposition of organic matter for at least two weeks, since their effect in most cases is not biocidal but rather biostatic. The use of 50 t/ha is recommended, which can be reduced through crop techniques such as application in furrows. The biofumigant should be uniformly spread so that foci of pathogens do not appear in the future. Then it should be immediately incorporated into the soil, tilled once with a rotovator and watered preferably by spraying until the soil is completely saturated (Bello 1998; Bello *et al.* 2003).

To control storage lifestages such as weed seeds, nematode cysts (*Globodera* and *Heterodera*) and fungi sporangia, biofumigation should be combined with solarization using plastic sheets that elevate and maintain the temperature and retain the gases produced by the decomposition of organic matter. It is an easy technique for farmers and technicians to apply, since it only differs from organic amendments in the choice of the biofumigant and in the method of application (Bello 1998; Bello *et al.* 2002).

After applying the organic matter, the soil and the irrigation system must be prepared. Shallow tilling could be done before planting. If the plot does not have drip irrigation it should be moisturized by sprinkling water. Then a plastic sheet is laid to cover the entire soil surface, to prevent non-disinfected spots along the borders. T he plastic should be well-sealed without cracks since the temperature attained is as important as gas and moisture retention. Clear polyethylene plastic of 40-50 microns is used to cover the soil. If the plot uses drip irrigation, once the plastic is in place, the soil should be humidified in several short irrigation periods during the following 2-4 days until about 40-60 $l/m^2$ is achieved.

### Biofumigation experience in vegetables

Various examples exist of biofumigation applied to tomato, cucurbit, pepper, lettuce and carrot crops, since it is a well known technique to Spanish farmers (Bello *et al.* 1996, 2003). Among the limiting factors, a possible 10-20% reduction in crop production can occur during the first two years compared to MB (Figure 1). There is also the cost of transporting the biofumigant which can be minimised with the use of local resources. Organic matter increases vegetation in the aerial part of the plant and a reduction in root production in carrot and potato crops (10-20%). Therefore, planting a leafy crop is recommended after biofumigation before a crop of roots or tubercles is planted (Bello *et al.*2003).

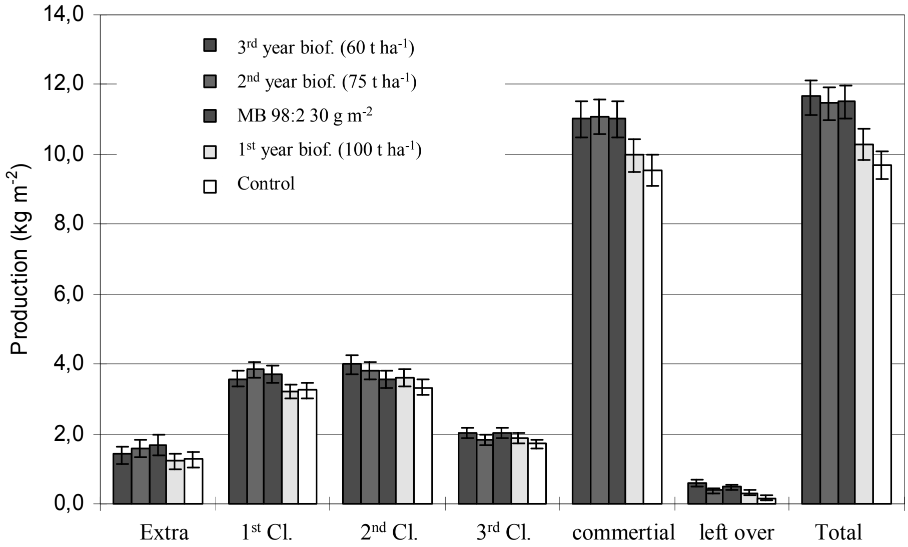


FIGURE 1: Average production by quality classes in 2000-01 campaign (Campo de Cartagena, Murcia, Spain) (Bello *et al.* 2001). LSD Intervals to 95% with Log 10(x+1) transformed data.

### Use of crop remains

The biofumigant effect of tomato, cucumber and pepper crop remains has been studied. The biomass that can be incorporated to the soil (Table 1) and its degradation after three months (Table 2) have been evaluated.

**TABLE 1: Biomass contribution according to crop (Mean of four replicates).**

| Crop | Stems | Leaves | Fruits | $kg/m^2$ |
|---|---|---|---|---|
| | % | | | |
| **Cucumber** | **40** | **50** | **10** | **2.50** |
| **Pepper** | **50** | **40** | **10** | **6.50** |
| **Tomato** | **43** | **27** | **30** | **11.00** |

**TABLE 2: Biomass decomposition (after 3 months).**

| Crop | Stems | Leaves | Fruits | Initial weight (g) |
|---|---|---|---|---|
| | % not decomposed | | | |
| **Cucumber** | **1.6** | **2.7** | **0.1** | **5** |
| **Pepper** | **30.0** | **5.4** | **0.3** | **20** |
| **Tomato** | **5.2** | **2.4** | **0.1** | **20** |

The majority is incorporated except for up to 30% of pepper stems which remain undecomposed. Biofumigation with crop remains does not affect soil fertility, although there is an increase in K content. So reconsideration of the fertilization programme is necessary. On the other hand, the addition of organic matter improves the physical and biological properties of the soil and, at the same time controls, nematodes, fungi and weeds.

**Biofumigation-solarization to control adventitious plants**

The first experiments to control adventitious plants started in the summer of 1997 in tomato greenhouses. At present, this technique is used in commercial crops as well as in the open field and under plastic nets. The solarization technique, alone or in combination with biofumigation, under Mediterranean climatic conditions has given excellent results in controlling weeds that extends throughout the entire crop cycle, in some cases up to 9-10 months. Biofumigation combined with solarization has even succeed in controlling some perennial plants such as *Cynodon dactylon* in 100% of cases, and *Cyperus rotundus*.

Previous crop remains and adventitious plants incorporated into the soil have proved to be a source of nutrients and organic matter that can be used for biofumigation. In this case, it is recommended to add fresh manure to enhance fermentation of such plant remains. Greenhouse trials have demonstrated that the dose could reach 100 t/ha when there is a serious problem, although in subsequent years that amount can be reduced to 45 t/ha for the 4$^{th}$ year without losing efficacy. Ongoing experiments show that these doses could be lowered in the 5$^{th}$ year and subsequently. As an alternative, the use of green manure can also be planned as a biofumigant.

**Economic issues**

In relation to tomato cultivation, a production increase of 36-41% has been observed in the biofumigation-solarization combination and MB treatments with regard to the non-disinfected control with the same amount of organic matter. In the case of pepper, the control plots were lost due to *Phytophtora capsici*. The biofumigated-solarizated plots produced a yield similar to MB (12 kg/m$^2$), when carried out before August 15. But when this alternative is applied at the end of August or the beginning of September, yield is lower than in the MB treatment.

Biofumigation cost per ha fluctuates between €510 and €858 for plastic sheets plus the value of 400-600 m$^3$ of irrigation water, which varies according to areas, and €210-540 for laying and removing plastic sheets. The total cost is much lower than the use of MB. Consequently biofumigation-solarization is an alternative to MB for developing countries (de León *et al*. 2000).

## CONCLUSIONS

Tomato and vegetable crops consume the largest amount of MB (8,180 t) in developed countries. MB's use as a soil fumigant could be reduced by changes in formulation (50:50 in controlled environments and 77:33 in the open field), dose (20 g/m$^2$), frequency (once every two or three years), VIF plastic utilization and strip application.

Alternatives to MB, besides being effective, must be compatible with international commitments on Biodiversity, the Kyoto Protocol and the Stockholm Agreement. One of these alternatives is biofumigation which is based on ecological criteria and the use of local resources. Moreover, its efficiency is enhanced when included in integrated crop systems.

Cucumber, pepper and tomato crop residues are effective in controlling Meloidogyne populations and weeds, but increasing efficacy with organic residues is recommended. Biofumigation also improves physical and biological soil characteristics. The recommended dose is 100 t/ha for the first year, when the problem is serious, decreasing in subsequent years to 45 t/ha for the fourth year. Higher doses could be reduced by using green manure. No phytotoxic effects are observed, or any other restrictions on production. Soil characteristics, as well as crop, region and type of organic matter, should be taken into consideration for field applications.

**Acknowledgments.** This work forms part of the INIA OT 03-006-C7-6 project: "Optimization and development of alternatives to methyl bromide: Critical use. Biofumigation," and the AGL2002-04040-C05-01 AGR-FOR project of the Spanish Ministry of Science and Technology: "Soil improvement by the use of crop waste amendments. Soil metabolism and their biofumigation effect." Ana Piedra Buena is supported by a Spanish Agency of International Co-operation (AECI) scholarship.

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# USE OF SUBSTRATES FOR INTENSIVE PRODUCTION OF VEGETABLES IN EUROPE AND MEDITERRANEAN REGIONS

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## ABSTRACT

Hydroponics, or soilless culture, is an ancient method of crop cultivation particularly for the cultivation of tomato, pepper, eggplant, melon, zucchini and watermelon crops. Worldwide, soilless culture covers an area of about 31,000 hectares, of which about 15,000 ha is in Europe. Soilless culture will become even more widespread in the future due to restrictive legislation on nitrates, restrictions on the use of methyl bromide, an increasing market demand for high quality produce and a decrease in the availability of labour and water for irrigation. Knowledge of the physical and chemical properties of the substrate is fundamental for effective management of irrigation and fertigation. The main substrates used in Mediterranean countries are perlite, rockwool, but pumice, pouzolane and other volcanic rocks are preferred since they are sometimes locally available. Peat is suitable for almost any horticultural crop but the price has increased and there is a growing interest in peat-lands for their natural and/or archaeological value. *Coir* appears particularly promising since they have properties similar to peat but its price is relatively high. The qualities of different substrates are discussed.

**Keywords**: Hydroponics, soilless culture, tomato, pepper eggplant, melon, zucchini, watermelon, methyl bromide, alternative, perlite, rockwool, pumice, pouzolane, substrates

## INTRODUCTION

The word 'hydroponics' is synonymous with soilless culture and includes all the techniques of artificial cultivation in substrate other than soil with the plants fed by a complete nutrient solution. This cultivation technique is used mostly for greenhouse crops and outdoor nursery stocks.

Soilless culture has a long history. The Egyptians, Chinese and Romans practised some hydroponic methods. However, from the commercial point of view, its improvement and application is quite recent as a consequence of improvements in our scientific knowledge of plant nutrition. Today we may consider hydroponics the most valuable technology for protected horticulture.

Today, soilless culture extends all over the world, especially in Asia, Australia and Northern Europe. The technique is becoming popular also in the Mediterranean countries (Spain, Italy, Turkey) either for the professional growers or kitchen gardens.

Solanacea (tomato, pepper and eggplant) and cucurbits (melon, zucchini, watermelon) crops account for more than 80% of the protected area grown with hydroponics as a result of the low plant density (ranging from 1.5 to 4 plant $m^{-2}$), the large market demand, their adaptability to variable climatic conditions of unheated greenhouses, and the extended growing cycle that enhances the exploitation of the greenhouse.

Soilless culture will become even more widespread in the future due to restrictive legislation on nitrates, restrictions on the use of methyl bromide, an increasing market demand for high quality produce and a decrease in the availability of labour and water for irrigation. Constraining the expansion of hydroponics is the huge investment cost, the lack of skilled labour and laboratories that rapidly analyse substrate and nutrient solutions.

Worldwide, soilless culture covers an area of about 31,000 hectares. In Europe, the main countries are The Netherlands and Spain (approximately 6,000 ha, roughly 90% of greenhouse acreage; Van Os and Stanghellini 2001) and Spain (approximately 5,000). In Italy, there are less than 1,000 ha out of nearly 30,000 ha of greenhouses. This is a limited area, since the worldwide surface of protected crops (greenhouses and high tunnels) is nearly 1.2 million ha, (0.8 million in China with only 1,000 hectares of soilless culture, of which about 60% is eco-organic soilless culture) and approximately 200,000 ha in the Mediterranean basin (Jouet 2001; Jiang 2004).

Hydroponics includes the technologies to cultivate the plant without any substrate, such as nutrient film technique (NFT) and floating system, or with artificial (inorganic or organic) substrate (aggregate culture).

The water culture system (NFT and floating) is used generally for short cycle crop grown at high density, such as leafy vegetables. Conversely, fruit vegetable crops (tomato, pepper, eggplant, cucumber, zucchini) and cut flowers (rose, gerbera, chrysanthemum etc.) are cultivated in bags, pots or benches differing in form and dimension and filled with different types of substrate, or in rockwool slabs (the Grodan® system).

## SUBSTRATE CHARACTERISTICS

The role of the substrate in soilless culture is to supply the water and nutrients and to provide mechanical support to the plant during the growing cycle. Therefore, for successful cultivation, knowledge of the physical and chemical properties of the substrate is fundamental for effective management of irrigation and fertigation.

Many type of substrate are currently available on the market with different physical and mechanical properties. They include peat, perlite or a combination of both to which may be added some other material in order to reduce cost and increase porosity. Other media such as coconut coir, sand, sawdust, and dregs of processed grapes, volcanic rock, pumice, absorbent clay and rice husk are used as well. The chemical and physical characteristics of some substrates for soilless culture are shown in Table 1.

Table 1: Chemical and physical characteristic of some substrates for soilless culture.

| Substrate | Bulk density (g/l) | Total porosity (% vol.) | Air capacity at 1 kPa (% vol.) | Available Water (% vol.) | Easy available water (% vol.) | Cation exchange capacity (meq/100 g) | pH |
|---|---|---|---|---|---|---|---|
| Black peat | 250-450 | 84 | 13 | 27 | 19 | 100-300 | 5.5-7.5 |
| Blond peat | 60-100 | 95 | 38 | 33 | 21 | 100-200 | 2.5-4 |
| Brown peat | 100-150 | 90 | 27 | 30 | 27 | 100-300 | 5-7 |
| Expanded clay | 600-900 | 85-90 | 40-50 | 35-45 | 10-15 | 70-120 | 5-7 |
| Peat-pumice | 400-500 | 82 | 25 | 18 | 14 | 50-100 | 5-6 |
| Perlite | 80-120 | 95 | 60 | 12 | 7 | 1.5-4 | 7-7.5 |
| Pumice | 650-950 | 70 | 30 | 7 | 5 | 0-2 | 6.5-7.5 |
| Rockwool | 80-90 | 97 | 15 | 78 | 77 | 0-2 | 7-7.5 |

Many of these media are manufactured in a different region to where they are used for crop production with the consequence that transportation cost can be quite high. Therefore, it is common for many growers to purchase those that are local to the region in order to reduce transport and overall production costs.

The environmental impact is one of the main problems that protected cultivation is today facing and some media are not environmentally-friendly, thus the re-use of waste materials should be taken into account.

An ideal substrate should have the following characteristics:

- Adequate mechanical properties to guarantee the stability of the plant;
- Low bulk density to facilitate the installation of otherwise weighty growing systems;

- High porosity (not less than 75-80%);
- An adequate distribution of air (oxygen) and water in order to sustain root respiration and plant water relations;
- pH between 5.0 and 6.5, or easily adjustable, like sphagnum peat that is quite acid but can be easily neutralised with calcium carbonate;
- Low content of soluble salts;
- Chemical inertia, that is the substrate should not interfere with the nutrient solution by releasing inorganic ions and phytotoxic compounds, or by immobilising nutrients, as it may occur for phosphorus and nitrogen in some substrates (Lemaire 1995);
- The ability to maintain the original characteristics during the cultivation, which may be quite long (for instance, for rose culture);
- The absence of pathogens and pests. The substrate does not need to be sterile.

One of the most important features of substrate is its hydraulic properties. In particular, the air and water retention at container capacity, which is the amount of water and, for difference, of air that is retained by the container after complete water saturation and free drainage i.e., when gravitational water has been lost. Substrate hydraulic properties are generally described by the water retention curve that measured as the changes in water content of a given volume of substrate as a function of water potential, as expressed in term of applied suction. The retention curve measures the substrate's ability to store water and give it to the plant. Several noteworthy criteria are derived from water retention curve:

- The water content at -1 kPa suction, very close to container capacity;
- The air content at -1 kPa, which may considered an index of the risk of root asphyxia;
- The difference in water content between –1 and –10 kPa suction, which represents the available water (AW);
- The difference in water content between –1 and –5 kPa suction, defined as Easy Available Water (EAW).

Another important physical property of substrate for pot cultivation is the capillary action which is the ability to absorb water from the bottom (sub-irrigation). Recently, sub-irrigation has been introduced for ornamental pot production due to its advantages over drip (top) irrigation such saving of labour, water and fertilisers, and greater uniformity of watering.

The extent of the capillary action depends on pore size distribution, the moisture content of the substrate as well as the surface tension of the irrigation water. In principle, dry substrate can absorb more water than moist media, but it will take longer.

Concerning chemical proprieties, pH and the cation exchange capacity are quite important. The pH influences the accessibility of the nutrients. The optimal pH ranges between 5.0-6.2. Normally, due to the alkalinity of irrigation water and the large use of nitrate-nitrogen in the fertigation water, the pH tends to increase during crop cultivation. In order to reduce this phenomenon, irrigation water must be acidified and a proper ratio between the nitrogen-forms in the mineral nutrient solution ($N\text{-}NO^-_3$ and $N\text{-}NH^+_4$) has to be applied.

The cation exchange capacity (CEC) of a substrate indicates its ability to keep the nutrients supplied by fertilization. In general, CEC is negligible in perlite, woody and mineral fibres. The lack of CEC may be an advantage since the control of plant mineral nutrition is easier. On the other hand, the absence of chemical buffer is a disadvantage especially when the culture is conducted by non-expert growers.

## THE SUBSTRATES USED IN THE MEDITERRANEAN COUNTRIES

For growing row crops such as tomato or rose, the most popular growing media are perlite and rockwool. Both are lightweight when dry, and easier to handle and sterilise with steam than many other materials.

*Perlite* is a siliceous volcanic rock that expands when it is heated to about 1000°C. For hydroponics production, perlite is generally bagged in opaque white bags of 20-30 litres with drip irrigation tubes at each plant and drainage slits in the bags. Perlite is an inert media providing excellent aeration and water holding capacity. It can be sterilised, re-bagged and reused several times, and afterwards used as a soil amendment.

*Rockwool* is similar to fibreglass. It derives from a mixture of volcanic rock, limestone and coke melted at 1500-2000°C and spun into fibres. The fibres can be granulated and used as a component of growing media or pre-packaged in ready-to-use plugs, blocks and slabs for germination, seedling growth and greenhouse cultivation, respectively. Actually, rockwool-growing technology constitutes a sort of reference system for greenhouse hydroponics cultures, notwithstanding the drawback caused by the disposal of used slabs. Like perlite, rockwool slabs can be used for several crop cycles, and afterwards they must be disposed because of the modification of its physical characteristics. However, discarding rockwool is more difficult since it is no degradable. In some regions, recycling or recovery options are not available to grower, and used slabs have to be removed to a municipal landfill.

In the Mediterranean regions, pumice, pouzolane and other volcanic rocks are widely employed without any particular treatment. They are cheaper than rockwool and perlite, the shipping generally representing the most important cost component for the growers. The main drawback of these materials is their low water holding capacity and poor stability.

*Peat* is suitable for almost any horticultural crops, but it used mostly for growing ornamental plants, propagation materials (seedlings, cuttings and micro-propagated plantlets) and, more recently, strawberry. High quality peat has low, manageable pH, adequate cation exchange capacity, high total porosity along with great water retention and aeration. Moreover, it is a lightweight material with lower processing and shipping costs than many other media components.

Peat consists of largely organic residues of mosses (*Sphagnum*), reeds and sedges that have been decomposed under anoxia conditions; it is produced primarily in the north of Europe and America. In commercial horticulture, peat is usually identified on the basis of the degree of decomposition. Light (blond) peat is the least decomposed; it has loose and coarse structure and very low pH, so that it has to be neutralized by addition of calcium carbonate. Compared to light material, brown and black peat have poorer structure for aeration and higher pH, nutrient content and salinity because of the more advanced decomposition.

Peat becomes hydrophobic when it dries out and therefore it may not be able to absorb the same amount of water as was lost through evapo-transpiration since the previous irrigation.

Peat has been and still is one of the most popular constituents of growing substrates protected horticulture. Nevertheless, the price of peat is increasing, especially in countries without peat resources, and there is a growing interest in peat-lands for their natural and/or archaeological value. This has produced an 'anti-peat' campaign in many European countries, particularly in United Kingdom (Holmes *et al.* 2000), and probably will lead to a drastic reduction of the availability and use of peat in favour of alternative substrates in the near future. In most cases, these materials are based on industrial or municipal waste by-products, which often do not have the properties of peat. This raises the need to study the proper management in term of irrigation, fertilisation and disease control. Nowadays the most interesting alternatives to peat are timber industry by-products, high-quality green compost and above all coconut-coir.

*Coir* products are particularly promising, since they have similar to peat with water retention slightly lower and pH around 7. The drawback of this material concern the reliability of supply and the risks of nitrogen immobilisation and salt toxicity.

As an example, the costs of some substrates used in Italy are shown in Table 2.

Table 2: Some substrates used in Italy for tomato cultivation. The number of water applications for day and the cost for $m^2$ are also reported. The simulation was produced assuming a plant density of 3 plant/$m^2$

| Parameter | Unit | Peat | Perlite | Rookwool | Peat-perlite mix (1:1) | Peat-pumice mix (1:1) |
|---|---|---|---|---|---|---|
| Bag or slab volume | L | 34 | 30 | 11,5 | 30 | 30 |
| Plant /bag or slab | N° | 5 | 5 | 3 | 5 | 5 |
| Available water | % vol. | 33 | 12 | 78 | 27 | 18 |
| Substrate volume | L/$m^2$ | 20.4 | 18 | 11,5 | 18 | 18 |
| Water content | L/$m^2$ | 6.7 | 2.2 | 8.6 | 4.9 | 3.2 |
| Irrigation | L/$m^2$ | 1.7 | 0.5 | 2.1 | 1.2 | 0.8 |
| Evapotranspiration | mm $day^{-1}$ | 3 | 3 | 3 | 3 | 3 |
| Irrigation frequency | N° $wateringday^{-1}$ | 1.8 | 5.6 | 1.4 | 2.5 | 3.7 |
| Cost | € $m^{-2}$ | 0.87 | 1.47 | 1.6 | 1.17 | 0.82 |

## CONCLUSIONS

Soilless culture in the future should increase steadily all over the world, although increases will be greater in the far East. In Europe and in the Mediterranean basin, the increase will be more limited due to their high costs.

It is true that the lack of MB will change the scenario as it use in crop production will decrease and its cost will increase. Nevertheless, the operator should carefully control any type of costs and substrate is one cost that must be controlled.

At the moment, peat substitution seems not to be such a pressing problem as the use of peat in horticulture is very small (0,36% of the total amount) compared to the amount burnt for energy. However, coconut coir seems to be a good peat substitute but its price remains high for low-value crops as an ideal substrate should have a good hydraulic property with a low cost.

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## DUTCH APPROACH ON ALTERNATIVES TO METHYL BROMIDE INCLUDING A NEW DEVELOPMENT: HOT AIR TREATMENT

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### ABSTRACT

Methyl bromide (MB) as a soil fumigant was completely banned in 1992 in The Netherlands. Several alternatives can be applied to control soilborne pathogens and pests. In field vegetables and arable crops, regulations in The Netherlands allow the soil to be fumigated only once in five years with metam sodium (MS). A recently-developed, Israeli technique of using hot air to treat open-field soil shows promise as a cost-effective alternative to MB that could be used when required for controlling soil-borne pests and diseases in cool climatic conditions. Research in the Netherlands that aimed to control *Meloidogyne fallax* showed no direct decrease in nematode population after the hot air treatment, whereas MS and steam sterilization reduced the population by at least 99%. In a bioassay, hot air treated soil and steam sterilized soil produced a higher tomato fruit weight than untreated soil. All treatments resulted in a lower root knot index. The viability of nematode populations exposed to hot air in the open-field may be reduced and this is currently being determined in a field trial with potato.

**Keywords:** Soil disinfestation, hot air, metam sodium, steam, substrate cultures, flowers, open field vegetables, arable crops, *Meloidogyne fallax*

### INTRODUCTION

Horticultural crops grown in the Netherlands in protected cultivation can be characterised as monocultures. The consequences are an increasing necessity for soil disinfestation due to soilborne pathogens and pests. Soil disinfestation by means of steam has been applied for more than a century. Initially, this method required heavy labour and was gradually replaced by soil fumigants. Methyl bromide (MB) was the most effective soil fumigant which was applied in greenhouses in the Netherlands on a large scale in the 1960's and 1970's. However, for public health reasons and because of negative environmental aspects the application of MB as soil fumigant was reduced from 1981 and completely stopped in January 1992 (Ministry HPPE 1992). Since then the best alternatives to MB in protected cultivation are steam sterilization of the soil or growing in substrates (Table 1). The latter also requires replacement or steam sterilization of the substrates after the growing period.

Table 1: Alternatives to methyl bromide used in the Netherlands in horticulture and agriculture

| Production type | Alternative | Crops | Area (ha) * |
|---|---|---|---|
| Protected cultivation | Steam sterilization | Chrysanthemum, fresia, lily, carnation | 1,166 |
| Horticulture | Substrate cultures | rose, gerbera, orchids, anthurium *Alstroemeria*, fruit vegetables | 5,828 |
| Open field | | | |
| Bulbs | Flooding, fumigation<br>Steam sterilization | Tulip, lily, hyacinth, narcissus, gladiolus | 24,538 |
| Vegetables | Fumigation<br>Biological, chemical and physical control methods | Strawberry, pea, bean, black salsify, cabbage, carrot, leek, asparagus | 45,725 |
| Arable crops | Fumigation<br>Biological, chemical and physical control methods | Root and tuberous plants | 262,100 |

*Netherlands & LEI-Wageningen UR, Agricultural and horticultural data 2004

These high-tech alternatives for the production of crops in greenhouses offer no feasible solution for open field cultures because they would be too expensive and impractical. Soil fumigation and flooding are frequently applied in open-field ornamental bulb production, although both methods are not always effective and controlling pests for different reasons (van Os *et al*. 1999). Occasionally, a mobile steam installation owned by a contractor disinfects the soil. Steam sterilization is very effective against all kind of soilborne pathogens (Runia 2000). However steam sterilization is very expensive because of the high fuel consumption (Table 2) and the low capacity of the machine.

Table 2: Fuel consumption of several physical disinfestation methods

| **Disinfestation method** | **Fuel consumption*** **(per $m^2$ soil area)** | **Soil depth (cm)** | **Application field** |
|---|---|---|---|
| Sheet steaming | 7 $m^3$ natural gas | 30-40 | Protected cultivation |
| Negative pressure steaming | 4 $m^3$ natural gas | 35-50 | Protected cultivation |
| Mobile steam sterilization | 1 l fuel oil | 25-30 | Open field flower bulbs |
| Hot air treatment | 0.1-0.2 l diesel oil | 30-35 | Agriculture, horticulture |

* The net heating value of natural gas and oil is comparable and approximately 36000±40000 kJ per $m^3$ or litre.

In field vegetables and arable crops soil fumigation is allowed once in five years. The only soil fumigant still permitted in the Netherlands is metam sodium (MS). Additionally a Nematode Control Strategy (NCS) is available for growers in order to cope with plant parasitic nematodes in their soils (Molendijk *et al*. 2004). This NCS comprises a complete information system with information about crop choice, crop sequence, crop frequency, the effect of green manure, black fallow, catch crops, hygiene, and additional measures such as soil disinfestation. Apart from this, the NCS presents information on host status which indicates the level of multiplication of certain nematodes on a particular crop and the sensitivity of crops to damage by plant parasitic nematodes (www.digiaal.nl, Beers & Molendijk, 2004). Resistant varieties against several soilborne diseases are also used.

In Dutch agriculture the most profitable crop is potato. This crop is grown in rotation with sugar beet, cereal and sometimes a fourth crop like onion. Harmful soilborne nematodes and fungi must be controlled in these crops. At the moment the restrictions in fumigant application and the lack of a broad-spectrum alternative hamper adequate soil disinfestation.

A new development in physical soil disinfestation is the application of hot air. The method has been developed in Israel and is applied in this country commercially for some years now. The method is based on blowing extremely hot air into rotavating humid soil. An optimal rate of hot air delivery and rotavator speed enables the temperature of each individual soil particle to be heated sufficiently to weaken or kill any pathogen or pest attached. The efficacy of hot air treatment in Israel was mainly established in commercial fields, infected with pathogenic nematodes or fungi. There were no scientific trials with statistical analysis. Nevertheless an improved growth in several crops like potato, cauliflower, kohlrabi and the flower *Esclepia* was observed. Pathogens may be still present in the soil after the hot air treatment but were thought to be weakened by the hot air and no longer viable to infect new crops.

The advantages are a sufficient capacity for protected as well as open field application and strongly reduced fuel consumption in comparison with any steam sterilization method. The capacity of the machine from Israel is at the moment 432 $m^2$ per hour, which means that 1 ha can be treated in 24 hours. Up-scaling the machine and its capacity is achievable.

For the first time, hot air treatment might be an economically feasible option for open-field soil disinfestations in temperate climates. In protected cultivation, it might be a low-cost alternative to sheet steaming and negative pressure steaming. For these reasons, the potential of a hot air treatment is currently under research as an economically feasible method for soil disinfestation of all field crops in the Netherlands. The trials aim to control the root knot nematode *Meloidogyne fallax*, the root lesion nematode *Pratylenchus penetrans* and the potato cyst nematode *Globodera pallida*; the fungal pathogens *Verticillium dahliae*, *Fusarium oxysporum* f.sp. *asparagi* and *Synchytrium endobioticum*, the causal agent of wart disease of potato.

This paper presents preliminary results showing the efficacy of open-field hot air treatment for controlling *M. fallax,* compared with MS and steam sterilization soil treatments.

## MATERIALS AND METHODS

A field was selected with a natural infection of the root knot nematode *M. fallax*. Three treatments were carried out in this field: hot air treatment, MS and steam sterilization. All treatments were performed in six replicates.

The Israeli hot air machine was transported to the Netherlands and used in all trials against the test pathogens mentioned. The air temperature of the blower was 720°C. The rotavator depth was about 30 cm. The speed of the machine was 240 m per hour. Israeli technicians operated the machine.

MS was applied in a concentration of 400 l per ha. A heavy roller closed the soil after the fumigant application in order to achieve an optimal effect.

A mobile steam sterilizer was used for the steam treatment. This machine cultivated the soil until 25-30 cm depth, then applied steam at 160°C to the soil. The capacity of this machine was 75 to 100 $m^2$ per hour. A heavy roller closed the soil after the steam application in order to maintain the heat in the soil as long as possible.

Soil samples were taken before the application of the several treatments in October 2003 and afterwards in March 2004 to establish the lethal effect on the nematodes. Counts are expressed in juveniles ($J_2$) per 100 ml of soil.

A bioassay in a greenhouse was performed with tomatoes planted in March 2004 in the untreated soils from this *Meloidogyne*-infested field. Twelve plants per treatment were used and 1 litre of soil was available per plant. Plants were kept in the greenhouse for three months during which time the growth of the plants was established. After this period the fruit numbers and weights were recorded and the root systems were assessed for quantity, quality and root knots.

The data were subject to statistical analyses using Genstat Windows (Payne *et al*. 2002). The data for the nematode counts were assumed to follow a lognormal distribution and the analysis was performed on the logarithm of the data. The back transformed means (medians) from these analysis are presented. When F-probability is smaller than 0.05 the differences are statistically reliable.

## RESULTS

The initial nematode population (Pi) before and the final population (Pf) of *Meloidogyne fallax* five months after the several treatments are shown in Table 3.

Table 3: *Meloidogyne fallax* population before (Pi) in October 2003 and after (Pf) several disinfestation methods in March 2004

| **Soil depth**<br>**Disinfestation method** | **0-30 cm**<br>**Pi** | **0-30 cm**<br>**Pf** | **30-50 cm**<br>**Pi** | **30-50 cm**<br>**Pf** |
|---|---|---|---|---|
| Hot air treatment | 1895 a | 399 . . c | 319 . b | 184 . . c |
| Steam sterilization | 981 a | 2 a . . | 40 a . | 19 . b . |
| Metam sodium | 2247 a | 22 . b . | 228 a b | 1 a . . |
| Untreated control | 1881 a | 472 . . c | 126 a b | 120 . . c |
| *F prob.* | *0.217* | *< 0.001* | *0.149* | *<0.001* |

The Pf is corrected for the covariate Pi. In the soil layer of 0-30 cm the numbers of nematodes in the untreated and hot air treated soil were the same and showed a natural decrease with approximately 80% during winter. Steam sterilization eliminated nearly the complete nematode population and also MS eliminated 99% of the nematodes. In the soil 30-50 cm deep, the initial population was much lower than in the top soil where the plant roots grow mainly. No lethal effect could be expected from the steam and the hot air treatment deeper than 30 cm because both methods heat only the top 30 cm of soil. The efficacy of MS is high in this trial.

The number of fruit, average fruit weight and the root knot index of the tomatoes is shown in Table 4. Hot air treated soil and steam sterilized soil produced a higher fruit weight of tomato, and MS showed the same fruit weight, in comparison with untreated soil. All disinfestation treatments resulted in a lower root knot index.

Table 4: Number of fruits, the average fruit weight and the root knot index of tomato

| object | # fruits per plant (n = 12) | fruit weight (grams) | root knot index (0 = no root knots, 9 = heavy root knots) |
|---|---|---|---|
| Hot air treatment | 2.4 a b | 13.9 . b | 5.72 . b . |
| Steam sterilization | 2.6 . b | 16.9 . b | 0.10 a . . |
| Metam sodium | 1.5 a . | 6.2 a . | 0.56 a . . |
| Untreated control | 1.9 a b | 5.6 a . | 8.17 . . c |
| *F prob.* | *0.187* | *0.002* | *<0.001* |

## DISCUSSION AND CONCLUSIONS

Steam sterilization and MS both had a direct lethal effect on the nematodes in the soil. Hot air treatment, however, apparently was sublethal to *M. fallax* in this trial. However, the hypothesis is that the population was weakened and will die out eventually, completely or partially exterminated by antagonists. This phenomenon was also established with solarisation in deeper soil layers (Katan *et al.* 1976). When this is the case, nematode counts shortly after hot air treatment are not a good parameter for the efficacy of the treatment.

In April 2004 potatoes were planted to establish the effect of the treatments on the yield which will be in October 2004. After harvest, soil samples will be taken again to establish the final population density of *M. fallax*. The impact of full or partial suppression of nematode populations due to the treatments on potato yield will be determined.

Hot air treatment is a very promising method for soil disinfestation, but further research must be performed to establish the possibility and limitations of this method under several climatic conditions. Thanks to the limited fuel consumption and a sufficient disinfestation capacity this method might be an economically useful alternative to MB for open-field as well as protected cultivation.

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# OVERVIEW: CHEHMICAL ALTERMATIVES TO METHYL BROMIDE USED FOR STRUCTURES

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## ABSTRACT

Several alternatives to methyl bromide (MB) fumigations are available for fumigation of grain storage and structures such as flour mill and food plants. Replacements for MB include phosphine formulations (e.g. $ECO_2$FUME™), sulfuryl fluoride (Profume™), carbon dioxide, and a Combination Fumigation Method. Characteristics and important advantages and disadvantages are reviewed. Reducing the need for fumigation utilizing proactive IPM strategies is discussed. The 482 tonnes of MB requested by the United States for critical use exemptions for use in mills and food processing structures for 2005 could be replaced entirely with technically and economically feasible alternatives that are described in this paper.
**Keywords**: methyl bromide, phosphine, sulfuryl fluoride, carbon dioxide, alternatives, structures, mills, $ECO_2$FUME, Profume™, Combination Method, IPM

## INTRODUCTION

Alternatives to methyl bromide (MB) for structures exist in developed and developing countries. Flour mills and food factories traditionally fumigate their structures one to four times per year. Today these structures are being treated with alternative fumigants and methods. Over 150 flour mills and food factories have used alternative fumigants in the United States in recent years. This represents a replacement of 130 tonnes of MB and more importantly many structures have reduced their frequency of fumigations with better fumigations and integrated pest management. The purpose of this paper is to overview those chemical alternatives that are in commercial use for these structures.
The proven alternatives for structures like flour mills and food processing facilities are:
1 Better grain fumigations
2. Sulfuryl fluoride fumigant gas
3. The Combination Fumigation Method
4. Intensive integrated pest management (IPM)

## MILL FUMIGATION PHASE-OUT

*The way to reduce the frequency of structural fumigations is to first do a better job of killing the insects in the grain before it is processed.*

*Grain Storage Fumigation -* Aluminium phosphide or cylinderized phosphine with recirculation system.

Hydrogen phosphide is the best alternative to MB for the fumigation of stored grain. It is a convenient, relatively safe, inexpensive and widely available chemical. Various forms of phosphine, including aluminum phosphide, magnesium phosphide, or cylinderized phosphine are used in the United States. Each formulation has its own advantages and cost differences.

Cylinderized phosphine ($ECO_2$FUME™) is an alternate phosphine formulation, consisting of a 98% carbon dioxide and 2% phosphine gas mixture under pressure. $ECO_2$FUME (EF) is registered in The United States, Canada, France, Australia, Trinidad/Tobago and is pending registration in countries in Europe, Asia, and Africa. EF has been used successful in grain fumigations for 20 years and in structures for ten years. The advantage to using EF is that the concentration can be controlled during the entire fumigation. Additional phosphine can be added to the fumigation if concentrations drop below a lethal level. An additional advantage of the cylinderized phosphine over the pellet formulation is that there is no residue (*i.e.* dust) in the finished product. The use of EF however, requires especially high pressure rated fittings and hoses. Monitoring of gas concentrations while using EF ensures the effectiveness of a fumigation.

The transition from MB to phosphine for grain storage fumigation must be carefully monitored to ensure that fumigation effectiveness remains high. Many grain bins are not air-tight. It is therefore important to ensure an adequate exposure of grains to fumigants, such that insects (at all stages of development) are killed. High fumigation efficacy can then be achieved faster.

Better grain fumigations can offer an immediate impact on the frequency of structural fumigations in developed and developing countries. By using this efficient method of fumigating inbound ingredients, the need for MB fumigations will be eliminated later in the supply chain.

## SULFURYL FLUORIDE

Experimental mill fumigants and recent full-scale applications of sulfuryl fluoride (SF) in flour mills, rice mills, and corn mills has shown that this new fumigant is a drop-in replacement for MB in this application.

Sulfuryl fluoride is a colorless and odorless gas under medium pressure (300 - 400 psi) and comes in tall steel cylinders that weigh 55 kg.

Registration was approved by the US EPA in January of 2004. Since that time over 50 commercial mill and food processing fumigations have taken place in the United States. These SF fumigations have replaced about 27.2 tonnes of MB. Sulfuryl fluoride (ProFume® fumigant gas) is manufactured by Dow AgroScience LLC., USA. There is another producer of SF in Europe. Sulfuryl fluoride is designed to replace MB in flour mills and food processing facilities. This product, unlike phosphine, is non-corrosive and has fewer restrictions than MB.

### *Advantages of SF over Methyl Bromide*

SF and MB share a number of chemical characteristics, namely that both fumigants are highly poisonous, non-flammable, non-corrosive, have low water solubility, need comparable exposure times (24 to 48 hours), and there is no known insect resistance to either compound. SF is not an ozone depleting substance and it is a better penetrating gas when compared to MB. SF has a smaller molecular weight which allows it to go into masses of finished products like rice, wood, stored grain, and other stored products.

SF is a proven structural fumigant. Vikane® has been used since 1956 to disinfest homes of termites. Over 250,000 homes are fumigated annually in North America with the fumigant. In January 2004, Dow AgroSciences received full registration for ProFume™ for structural fumigations including dried fruits and nuts, flour mills, cereal factories, and other food processing and warehousing structures. Food tolerances were set at 124 ppm of fluorine residues in finished foods. The average concentration of fluorine from one fumigation at the highest dosage rate is 18 ppm, according to Dow's research.

SF kills all stages of insect life when used in accordance to the label. Increasing the heat in a structure would add to the effectiveness and lower the amount of fumigant required because the respiration of the targeted insects increases with increased temperatures.

Resistance to phosphine has shown to be a potential global problem. SF has a different mode of action than phosphine. If resistance becomes a problem, the number one MB alternative, SF could readily replace phosphine. This would prevent a need to return to the ozone depleting substance MB.

Shutdown time is very important in any operation that runs 7 days a week and 24 hours per day. A flour mill grinds wheat into flour year round. It costs about US$60,000/day to shut down a flour mill in the US and many times over $1,000,000 /day to shutdown a food processing plant. SF fumigation, of the use of phosphine+heat+carbon dioxide, result in shutdown periods that are shorter or equal to that of MB.

### Disadvantages of sulfuryl fluoride compared to methyl bromide

SF is a new fumigant in food factories. The cost of this application is presently 30-40% more expensive than MB. More sealing of the building is required to help retain the gas in the structure.

More monitoring is expected because the amount of fumigant required is based on a calculation of concentration-time (CT value). The CT is determined during the fumigation after a gas sampling has be taken and calculated. The efficacy for SF is similar to MB. ProFume™ is registered in 47 states in the US (California is pending). The incremental cost difference comes in the training, additional labour, improved sealing and monitoring that needs to occur to maintain lethal gas concentrations.

## CARBON DIOXIDE FUMIGATION

Carbon dioxide ($CO_2$) can be used as a synergist at levels of 2-5% (20,000-50,000 ppm) to help speed up the respiration of pest insects and rodents. This stresses the pests and they eventually die faster than normal. $CO_2$ is difficult to use and can be very dangerous to humans. It has a niche in structural fumigation and should be considered.

$CO_2$, a naturally occurring inert gas, is listed as an approved organic technique for fumigating commodities and museum items. It can penetrate readily into a mass of commodity like bagged grain. $CO_2$ is highly toxic at recommended concentrations of 40-60% (400,000-600,000 ppm). It dehydrates insects and causes death by desiccation. A disadvantage of using $CO_2$ is that it would take 7 to 21 days to kill pests. An additional drawback of using $CO_2$ is that the cost of fumigation is ten times that of MB fumigation.

## COMBINATION FUMIGATION METHOD

In this method, cylinderized phosphine, heat, and $CO_2$ are used in combination (called the Combination Fumigation Method, CFM). MB is a quick acting biocide. Phosphine, conversely, is normally a slow acting cellular poison. Phosphine fumigation can be accelerated by using EF which releases phosphine 12 to 24 hours faster than aluminum phosphide. The $CO_2$ acts as a fire retardant, but also has synergistic properties when concentrations reach 2-5% by volume. $CO_2$also helps dry out the insect by allowing the breathing apparatus called spiracles to stay open longer.

CFM uses 50 - 100 ppm of cylinderized phosphine along with increased daytime and nighttime temperatures of 35 - 40°C for 24 – 36 hours. Experimental and full-scale fumigations of flour mills and food processing plants have shown this method to be highly effective against all stages of insect life. Over 70 applications of CFM have been performed to date in Europe and North America. Over 100 tonnes of MB have been replaced with the CFM on flour mill and food processing structures without problems with corrosion. Levels of phosphine below 100 ppm have been shown to cause minimum corrosion problems to electronics and sensitive copper containing products.

### Disadvantages of combination fumigation over Methyl Bromide

Phosphine can corrode copper and electronic equipment at high concentrations (above 100 ppm). The cost of phosphine and heat in a flour mills and food factories has shown to be similar to the cost of MB fumigations (US$ 18.00 /1000 cubic feet, equivalent to €14/28.3 $m^3$). In many cases it is less expensive after the initial fumigation. As the price of MB continues to rise, the cost comparison with CFM will decrease. Most flour mills have a boiler system to produce their own electricity. These boilers would be retrofitted to heat the mills during the CFM. Extra monitoring and vigilance is needed in all advanced MB alternative applications.

## INTEGRATED PEST MANAGEMENT

IPM is a proactive way of reducing the need for fumigations. It takes specially trained technicians to truly accomplish the end result of zero insect tolerance. This site specific programme should include the following recommendations and proven pest management techniques. If a company spends more time and resources on *prevention* and *monitoring* pest problems they will, in many cases, be able to reduce their dependence of chemical fumigants. Here are some important IPM practices:

**Screens -** All windows and doors should have screens and barrier strips installed to keep insects and birds out of warehouses and grain processing structures. Flour mills need large amounts of air exchange to balance the air needed to pneumatically move the stock in the milling process. Simply put, closing windows and doors helps keep pests out of a structure.

**Inspection -** A survey of the structure should be performed by a qualified pest manager. The collection of data to establish baselines to compare future progress or regress is important. This inspection will detect the presence and absences of defects in the system and proper corrective action can be applied when the time is available. Third party auditors are available to assist this important IPM step.

**Insect monitoring program -** This technology should be a part of any stored product IPM programme. Perimeter trapping of the boundary line for stored product insects is important because of the natural outdoor population established near grain handling and storage facilities. An indoor pheromone monitoring program will provide important information on what type of control needs to be applied, if any.

**Rodent control program -** Approved rodent devices and rodent bait boxes with registered rodent baits should be placed uniformly indoors and outdoors in food storage and processing locations.

**Residual insecticide application** – Low impact insecticides like Cyfluthrin (synthetic pyrethroid), pyrethrins and insect growth regulators (IGR) are used in flour mills. They are delivered with a sprayer and can be applied to most areas of the mill or food factory (exception-food contact surfaces). These insecticides have a low impact on workers and food products. They carry a caution label (lowest toxicity).

**Bird control** – Birds can be big problem in food storage processing and storage. Truck doors and dock doors are often left open. Screens and barriers are needed on these openings to exclude these serious pests that mess on food products and harbor diseases.

**Vacuuming** – Good hygiene is the biggest part of any IPM programme. Removing food sources will offer conditions unfavorable for the growth and development of pests. Vacuuming the stacked bags is a preventative measure that will lead to less pest problems and better quality products. Vacuuming also removes bird droppings and feathers.

**Education, Education, Education** - Educational seminars and continued educational workshops designed to offer proven phase-out options of methyl bromide are essential. The licensing of fumigators by requiring minimum requirements can make alternatives available to these stakeholders while sharing valuable practical experiences and technology. Continued education will help make the phase-out of MB sustainable.

## INSECT RESISTANCE MONITORING

Since phosphine fumigants are an important alternative to MB in grain storage and structures, it is essential that phosphine resistance to insects be closely monitored, recorded, and corrected.

If a phosphine fumigation failure is observed, samples of insects should be collected and sent a resistance laboratory to be tested for phosphine resistance. There are moderate levels of phosphine resistance being detected throughout the world. Dosage rates can be adjusted to kill resistant stored product insects if resistance is detected or a fumigant with a different mode of action can replace phosphine until resistance levels are back down. This programme is required for zero insect tolerance on imported and stored raw commodities prior to milling. To have a pest free structure a well fumigated grain stock is essential.

## FUTURE CONSIDERATIONS

In the United States much depends on who is elected in November as President and environmental leader of this influential country. The Bush Administration has a history of dismantling environmental treaties. This could have a major impact on the future of the Montreal Protocol and how we do our job. The current critical use exemptions (CUE) are excessive in the United States. The 482 tonnes of CUE of MB allocated for mills and food processing structures in the US for the year 2005 could be replaced entirely with the MB alternatives mentioned in this paper. The current stock piles of MB in the US are excessive and growing. The good news is that individual people are getting better at finding ways to replace MB. If given a menu of alternative options, these individual stakeholders can make the transition much easier. Government registration of new products and similar products needs to be truly 'fast tracked' to offer more options. Change is hard for some people; especially farmers. But there is a price to pay for protecting the environment. Individuals are starting to understand that man has done something to harm this planet in the last fifty years with this use of ozone depleting substances and it is man's job to correct this problem.

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# FOOD PROCESSING SANITATION
# TOP PRIORITY FOR CONTROLLING PESTS WITHOUT METHYL BROMIDE

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## ABSTRACT

Sanitation in food processing facilities is one of the most important management tools for avoiding insect pest problems. It is necessary to know where insects might enter a facility and what types of insects might be present. A sanitation programme must define the areas and lines that are part of the programme, the frequency of cleaning and inspection, the method of cleaning, personnel responsible and verification procedures. Cleaning equipment can include a range of vacuum cleaners with variations in equipment and operation. Preventive measures include IPM techniques, pest proofing, and a range of treatments. Employee training in connection with Quality Assurance systems is essential. Examples of food companies that have not used methyl bromide or other fumigants for disinfestation for many years in Greece are provided. Effective sanitation programmes remain a valuable target to be achieved by all food processing facilities.

**Keywords**: Sanitation, documentation, verification, insect entrance points, preventive measures, training, methyl bromide, alternative, phosphine, quality assurance

## INTRODUCTION

Sanitation is a very important pest management tool. It removes food remains reducing sources for insects and it removes the insects themselves. Sanitation is required by the Good Hygiene Practices (GHP), it improves the working environment for the employees, it reduces the possibilities of food contamination and it is harmless for the food, the workers and the environment. Usually is very inexpensive as well.

Sanitation is often regarded as a compulsory step to follow production and is performed by untrained employees. On the contrary, it should be regarded as an important part of Pest Management because firstly it can eliminate an insect threat if performed correctly, and secondly, the remains of insects in collected dust and debris are proof of insect infestation.

Case studies show that Sanitation has a primary role in companies who are seeking ways to avoid or minimize fumigation.

## WHERE ARE THE INSECTS?

Before we set up a sanitation program we need to know what insects could be expected, what is their biology and habits and how can they enter the facility. As Dave Mueller insists “we must start with the insect first”. We must know what we are looking for.

### Most common insects in Mediterranean countries

For example, beetles belonging to the genera *Sitophylus*, *Tribolium*, *Oryzaephilus* would be hiding in wooden floors and in food spoilage. They very often develop in stored cereals in silos or warehouses. *Lasioderma sericorne* is found in tobacco and *Stegobium paniceum* is found in coffee, books and in bakeries. Moths (like *Plodia interpunctella* and *Ephestia elutella*) are commonly found in cereals, in packaging material or in cracks and crevices.

**How do insects enter the facility?**

In raw material: All insects are more easily seen while in the adult or larval stage because they have a larger size and are moving and eating. While receiving bulk or packed raw material we would expect to see them crawling on the truck walls, preferring the sun and the areas with most broken seeds and dust. On bags, we can spot them on the bag “ears” or between bags.

In raw material in our silos: An infestation can develop in our own silos. Treatment of empty silos, inspection of received material, pheromone monitoring are preventive tools.

In empty trucks or packaging material: Empty trucks or packaging material can also be sources of infestation. Inspection shall take place and prior loads shall be recorded.

In returned products: Products which are returned for quality or expiration reasons can be infested as they were stored in non-controlled facilities.

They enter the front door: Insects can develop in fields or garbage near the installation and enter through doors, windows and openings. Insect screens, plastic or air curtains and personnel training are common ways to stop insects from entering.

**Inspections**

At regular intervals, experienced inspectors should carry out audits in all areas, looking for signs of infestation. Sieves, wooden floors, silo chain and screw conveyors and conveyor blind ends should be on the inspection list.

## SANITATION PROGRAM

Select the areas and the lines to be included as this is the first step for setting up a sanitation programme. The best scenario involves all the equipment of each room. However in certain facilities, some pieces of equipment require specialized opening and cleaning to be performed only by trained personnel.

Frequency. This is determined by experience, timing, personnel availability and infestation risk factor.

Sanitation method. This includes the equipment to be used, the chemicals, the dosages and the phases.

Responsibility. Note who is trained to undertake the sanitation process and who will inspect when finished. Include a scenario with corrective actions.

Verification procedure. Sanitation can be verified by microbial test kits, or by pheromone systems.

***Cleaning Equipment***

Several types of equipment are available on the market. A few are mentioned here:

- Vacuum cleaners with correct volume and power. With safety switches for dust extraction. With filters and bags. For optimum mobility. Wet or dry cleaning. Hot or cold water. Drivable sweepers.
- Color coded brushes and sweepers, scrapers and scoops.
- Sack holders and waste bins, internal external, pedal operated, mounted or wheeled.

## PREVENTIVE MEASURES

Certain systems which are normally called prerequisites are implemented to prevent insect entrance and infestation.

Such systems are: The use of Integrated Pest Management (IPM) techniques, the use of specific equipment to make the buildings pest proof and the insecticide treatment of screenings, vacuum bags, empty waste bins etc.

**IPM techniques**

Insect Monitoring by Pheromone traps: Selection of correct pheromones, placement, recording of catches and evaluation by professionals.

Insect Suppression by Pheromone traps: Selection of correct pheromones for male and female adults, placement, recording of catches and evaluation by professionals.

Insect Suppression by Ultra Violet light traps: Selection of correct light traps with glue boards, placement, recording of catches and evaluation by professionals.

**Equipment for Pest Proof facilities**

Window insect screens: removable, washable weather resistant.

Air curtain: Air conditioner or blower placed on top of a door creating a continuous current that makes it impossible for insects to fly in through an open door.

Plastic curtain: Industrial type heavy PVC lines that cover the entire door opening.

Positive air pressure: Specialized air blowers maintain a positive pressure inside the buildings. When a door opens insects (and dust) are unable to fly in as there is a strong opposite air current

**Treatments**

All sieve screenings, vacuum bags and waste bins have high probability of containing insects. They should be treated regularly with insecticides before they spread an infestation. Techniques used are fogging, spraying and chamber fumigation.

## SANITATION AND QUALITY ASSURANCE SYSTEMS

Sanitation is a legal requirement. It comes under HACCP which is obligatory for the food industry. This is a part of Directive 93/43 for the EU and also it is a requirement of the Codex Alimentarius for the rest of the world

Several QA systems are applied around the world. When we come to the food industries all QA systems refer to GHP and to implementation of the laws.

For **HACCP** sanitation comes under the prerequisite programmes with IPM, Maintenance and Personnel Hygiene.

For **ISO 9001** or 14001 it comes under the requirement for obeying the law.

For **BRC** (British Retail Consortium) it comes under § 3.9 'Housekeeping and Hygiene' and under § 3.10 'Waste / Waste disposal'.

For **IFS** (International Food Standard) it comes under § 4.9 'Housekeeping and Hygiene' and under § 4.10 'Waste / Waste disposal'.

It is a legal requirement and a QA system is required to have a sanitation procedure, to implement it, keep records and to evaluate its efficacy.

## TRAINING

To improve the sanitation efficacy and increase the workers awareness certain things must be undertaken during training:

Selection of training subject: Clean In Place (CIP) or Clean Out of Place (COP) instructions, cleaning chemicals – use and dosage, Vacuum Cleaners – use & maintenance, pest proof buildings, pest identification and reporting.

Selection of speaker: Internal training by supervisors, internal training by people who attended seminars, external training by specialists.

Evaluation of training: By evaluating the workers' improvement and by workers evaluating the speakers.

## CASE STUDIES FROM GREECE

Sanitation has always been an essential tool for Greek companies because as the Mediterranean climate is mild, no constructions are made airtight. And keeping the fumigant in has always been difficult.

**Papadopoulos biscuits** – No fumigation at all. Sanitation with vacuum cleaners and wet cleaning. Fogging of wheat flour silos. Inspection of all received raw material. Rejection upon finding of only one insect. No MB since 2000.

**Amylum Hellas** – **Tate & Lyle** No fumigation at all. Sanitation with vacuum cleaners and wet cleaning. Fogging of corn silos. Fumigation of final product (starch) not needed any more. Set up of new floors helped to eliminate pest harborage. Inspection of all received corn loads. Rejection upon finding one insect. No MB fumigation since 1999.

**Euricom Rice Mill** – This mill was built in a way that it cannot get airtight. Since 5 years ago they implemented vacuum cleaning and daily inspections. Final products are often fumigated with phosphine under tarpaulin or in containers. All doors have plastic curtains and all paddy rice is fumigated in silo with the use of phosphine.

**Soya Hellas / Nedera – Cereals, pelleting and oil refinery –** Fumigating of cereals in silo with phosphine. Vacuum cleaning per day. Pheromone monitoring per week. Spot spraying with low impact insecticides on problems. No MeBr since 1998.

**Ferro – Baked products** – This is a complex story as the production lines are old and difficult to clean. A n hour is spent on a daily basis for cleaning the lines and there has been no fumigation since 2002.

**Fakiridis – Flour Mill** – Privately owned silos are fumigated by specialists with the use of Phosphine. Sanitation under strict schedule especially after HACCP certification. One fumigation per year with the use of Phosphine. No MB since 1998.

**Thrace Mills – Flour Mill** – Vacuum cleaning of rooms and lines. Two fumigations per year with the use of MB. As a part of HACCP system a new IPM system has been recently set with emphasis on pheromones. AgroSpeCom has the intention to prove to the Mill Quality Manager that the two fumigations are not necessary and we will have no insects with the combination of Sanitation and IPM. Our target is to have one fumigation in 2005 and no fumigation for 2006.

## FUTURE CONSIDERATIONS

In Greece, the situation has not changed significantly in the past 5 years. The mills that are fumigating with MB continue to do so with few exceptions. The main use for MB is for quarantine fumigations of shipping containers travelling to USA, Canada, Australia, Egypt and elsewhere. As specified in the Montreal Protocol, MB can continue to be used for such quarantine and pre-shipment (QPS) purposes.

MB is becoming difficult to obtain and expensive. But still those who wish to find it, they can through other countries etc. Only 1-2 fumigation companies (not AgroSpeCom!) are piling cylinders for future use. As clients become more and more demanding and HACCP is a law requirement, Sanitation will become an essential element of all food factories. Good sanitation remains a target to be achieved for all us who play a consulting role in the food business.

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## COMMERCIAL USE OF SANITATION, IPM AND HEAT FOR DISINFESTATION OF FLOUR MILLS AND FOOD PROCESSING FACILITIES

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### ABSTRACT

For decades, Integrated Pest Management (IPM) has been successfully applied in many areas of pest management. IPM combines multiple tools or techniques to achieve control of a pest within a select environment. The method of combining sanitary design, sanitation techniques and an "in depth" understanding of the pest biology and habits is an extension of IPM. Completing the puzzle by applying heat, often to just part of a food processing facility, as the final control helps us to create a non-chemical approach to managing stored product pests. More correctly titled Urban Integrated Pest Management (UIPM), this term could be applied to structural as opposed to agricultural situations. The original work in this area was undertaken in order to find alternatives to MB. Additional pressures on our society to reduce pesticides wherever possible have extended this work. It has evolved into something far more intensive than originally intended but the results have been dramatic in many different facilities. At this time our company has completely eliminated the need for MB in all of our client's milling and bakery operations. This paper highlights the steps required to encourage facilities to adopt such measures.

**Keywords:** Integrated Pest Management (IPM), sanitary design, best biology, sanitation techniques, heat treatment, MB, non-chemical.

### INTRODUCTION

Methyl bromide (MB) is scheduled to be phased out in 2005 thus placing pressure on the structural food processing and milling sectors to find cost effective alternatives. My work with this extension of IPM started in 1992 when the industry was informed that we would most likely lose MB as our primary control tool. With little faith in fumigant alternatives due to their registration volatility, I decided to work diligently with a couple of bakery food processors to see if it would be feasible to clean a facility enough to limit the size of an insect population and then apply small scale treatments such as heat treatment to eliminate those critical zones. This theory was based on the known ability to stress pest populations and reduce insect development. As this technique evolved and monitoring / data collection equipment has improved, greater strides have been made at measuring insect distribution and densities. This has improved results over the past several years.

This method is effective on any type, size or condition of facility. It has been used to control all types of stored product pests and in any type of geographical area. Over the past decade, these methods and theories have been used around the world. The costs of implementation will vary greatly from facility to facility depending on what level of infestation exists, the clients expected level of control and the condition of the facility. Experience has shown that facilities feel confident in the process. In every facility where I have implemented this process, all are still using the theories and feel that their overall costs have decreased as opposed to increased. The difference is the overall costs now incorporate areas that were previously not considered pest related, such as production and sanitation budgets. Although the overall reduction in recorded MB use is still considered small, as pressure increases to find non-chemical alternatives, more and more facilities are turning towards this methodology.

### IPM IN FOOD PROCESSING FACILITIES

#### Pests and facilities

This technique has been built around control of stored product pests within bakery, milling and other kinds of food processing and storage facilities. Since stored product pests have a relatively predictable biology, including life cycle and habits, a control strategy can be implemented that remains consistent. Although, each facility is unique this programme can be adapted for any type of structure, whether new or old, constructed of any type of material and in any condition. The largest variables are the degree of cooperation, level of infestation and length of time the facility has set to achieve the desired level of control.

The first step is to correctly identify all of the types of pests that exist within the facility. Many facilities have, in the past, incorrectly identified the insects. Due to the fact that fumigants are non-discriminating in what type of insect that they kill, correct insect identification was not as important to the control strategies. Since we are using for control the insects' weak points in its biology, it becomes imperative to correctly identify the pest.

Once all of the pest species have been correctly established, a population density assessment needs to be undertaken. This can be performed, in most cases, through the use of pheromone monitoring devices. Most stored product pests respond well to these traps and good information can be quickly accumulated to determine the parts of the facility that will require immediate attention. I would recommend the implementation of a bar coding programme to collect information from the traps as a lot of data can be compiled quickly. These data need to be placed on trend reports and each individual trap will need to be uniquely identified within the structure in order to be able to perform history checks on specific traps. These history checks and trap trends are critical to determine whether or not your strategies are working within select areas (zones).

**The team and its role**

This type of control strategy requires a team. That team must be comprised of the following people or departments. In some smaller facilities many of these functions are combined making the decision process less complex:

1. General Manager – oversees programme process and is required for decision making on procedural or structural changes. Also reports activities to upper management.
2. Quality Assurance (QA) – responsible for reporting any insect occurrences and generally has authority to shut down sections of facilities when insect presence is detected. Also generally responsible for development of quality programmes and systems
3. Production – authorises any changes to equipment or line down time during the regular schedule. Controls whether or not sufficient time is available for Standard Sanitation Operating Procedures (SSOP's) and Preventative Maintenance (PM's).
4. Sanitation Manager – Understands the viability of the SSOP's and where they can be quickly adjusted in order to accommodate other departments or schedules.
5. Maintenance Manager – Understands the PM's and their required schedule. Must work closely with the sanitation manager.
6. Pest Management Professional (PMP) – Understands the pest and where it's found within the specific facility. Needs to work closely with all other departments.

This team will meet weekly for the first 3 months of the programme. These meetings will concentrate on specific issues and responsibility will be assigned to each issue. These meetings should be driven by QA, minutes taken and responsibility assigned to each item. Once the team establishes itself the meetings could be reduced to monthly.

It is critical that the team stays focused on the improvement of procedures and sanitary design. The team will also be responsible for review of any structural or equipment changes that are to be implemented within the facility to ensure that new equipment meets sanitary standards and that any contracting that is performed within the facility will improve conditions.

**Developing SSOP's, PM's and Training**

Most facilities have some type of procedures to direct staff on how to perform either a task of cleaning or maintenance. Unfortunately, most facilities did not consider pest biology in the design of these tasks. These tasks will need to be re-assessed by the department head in conjunction with the pest management consultant.

The pest management consultant will need to perform cleaning work on each of the line(s) or processes to understand where the procedures are working or need improvement. Adjustments will be made after the consultant has confirmed what additional duties need to be performed in order to better stress insect populations.

Average life cycles of stored product pests tend to be greater than 4 weeks, so schedules should start at a minimum of 4-week cycles. It is common to increase total sanitation hours in certain areas but decrease them in others. It is also common for sanitation hours to increase in the short term until employees become accustomed to retraining their vision towards being “insect clean”.

Once new procedures have been developed they need to be adjusted regularly due to process changes and equipment changes. It will be critical to ensure that responsibility and accountability are paramount in the eyes of the supervisors. These procedures are a critical function in the success of this programme and they must be taken with the utmost seriousness. They should never be signed off if the work has not been completed, as this will change the schedule enough to permit insect reproduction.

All maintenance, sanitation, production and pest staff will need to be trained to identify the known pests. They will also need to be trained on how and where to find these pests. This will include pictures of areas in which the pests have been found during the process work that the pest consultant has performed in the facility. These pictures should be of both the problem and of the solutions so the staff can start to adjust their thinking and vision while they are performing tasks throughout the lines. The training should consist of 1 hour “in class” sessions for all groups independent of one another. That way the consultant can concentrate on issues directly related to the group’s area of responsibility. Pictures can be taken that are directed towards specific issues relevant to the department e.g. Equipment design for maintenance.

**Structure**

The quality of the sanitary design of the structure will have direct impact on the speed at which you can achieve your pest reduction goals. The facility needs to be carefully assessed and prioritized. Your consultant will need to have practical sanitary design background. There is no merit in detailing areas in which insect activity is not present as the list is usually large enough in the critical areas. I have always found that choosing a few small changes makes a good impression and builds confidence for the larger changes that will undoubtedly exist. Look for issues such as open wall voids, improperly sealed floors, lighting, poor drainage and incorrect construction materials. To a trained eye, there will be thousands of hidden pest harbourage areas. It will be critical to know which ones will have the greatest impact for the least money.

This “wish” list will be presented to the Pest Team and justifications will be created. Some of these issues may have capital requirements. Unless a facility is trying to “fast track” itself to achieve certain goals, capital costs usually take several years to get approval. Although many of the consultants’ changes are related directly to pest issues, there are always other issues that will be affected. The objective is to find as many other team members to identify if the change would have a positive effect to their department. Once enough support has been rallied, the change will be easier to justify. My experience has shown that there always seems to be money for projects when enough departments have justified its need.

**Equipment**

Similar to the condition of the structure, equipment design will have a significant impact on the speed at which the facility will achieve its goals. Changes to equipment, however, have a much greater impact at the speed of which control of specific pest issues will be achieved.

The consultant will evaluate the sanitary design of each piece of “critical” equipment. These are pieces that are either difficult to clean or can’t be taken apart on a regular basis. Many pieces of equipment may be poorly designed but easily modified. The golden rule of equipment design is it should be easily accessible for cleaning. This means every part from the motors to the dust collection. Concentration should be placed on areas that are not regularly disturbed such as auger ends or motor housings.

When in doubt on whether to seal up an area or open it to permit cleaning, open it if the design will permit it to be opened. Sealing of anything in a dusty environment is very difficult. Caulking and silicones always wear out and pull away from the surfaces on which they are attached, leaving small gaps for both flour dust and insect reproduction. My experience has shown that the greatest success with creating good seals on steel equipment is by solid welding joints.

Equipment needs to be designed in such a manner, that dust falls down without being trapped on ledges or voids. Any areas that can't be designed or modified to permit dust to fall downward, need to have easy access for cleaning. This may mean creating access panels or replacing solid guards with grated. There are many books on equipment sanitary design and the majority of the changes do not cost a lot of money.

As with the structural changes, the equipment "wish list" will need to be presented to the pest team. These benefits of these changes will need to be justified. Here more then structural, the changes will have a significant impact on both the maintenance and sanitation departments. Many of these changes will make the job of cleaning and maintaining the equipment easier.

Remember that each type of environment will have its own set of sanitary design criteria. Wet process equipment is not designed for dusty environments and *visa versa*. Your recommendations must be specific to the facilities environment. New equipment must meet certain sanitary design criteria. I have found that there is little to no cost difference to well designed equipment verses not well designed equipment. It is only a matter of the facility making the right choice.

**'Zoning Down' the treatment areas**

Once you've become familiar with the facility, it's procedures and it's equipment, you will need to 'zone it down' into priorities. This is accomplished by eliminating infestation areas by one of the three previously mentioned techniques. At that point, you will be left with 1/ Equipment that can't be replaced or modified; 2/ Structural changes that are too costly or impractical; 3/ Timelines on structural or equipment changes that are delayed for a variety of reasons. These "zones" usually make up a very small percentage of the overall plan for the facility. These "zones" will require alternative measures, either short or long term, to control infestation. These alternative measures may be either chemical or non-chemical in nature.

I prefer to try non-chemical measures, wherever possible to keep the facility working towards a pesticide reduced mindset. History and ample research has proven that stored product insects can be killed with the application of heat. There has been much debate about the effects of heat to structures and the costs of converting the facility to permit heat to be used as a control. These debates are quickly being negated as more and more research on insect behaviour and development of improved heating techniques prevails. I don't disagree that the cost to convert an entire facility to heat is difficult to justify but I have yet to see any facility that needs its entire structure to be placed under a heat treatment. Utilizing the previously mentioned techniques will reduce the average facility to the point that only 5 – 10 percent will require any kind of alternative method at any one time. This makes the conversion cost to heat very attractive. In addition, unlike chemical alternatives, most facilities can remain in production, in areas not being heat treated. This means reduced down time and improved productivity.

The future of heat treatments as a non-chemical alternative will be in "zone" treatments in order to take advantage of both the reduced initial conversion costs and more importantly the ongoing lost production costs.

## ACCEPTANCE BY REGULATORS

Consumers are increasingly concerned about the use of pesticides in processing and warehousing of all types of food. Many food facilities are reducing reliance on pesticides in response to consumer and regulatory pressures. IPM programmes that rely on monitoring, inspection, cleaning and non-chemical methods are very acceptable to the public. In addition, the use of heat in place of many chemical applications is far preferable from a regulatory aspect.

## APPLICABILITY TO OTHER COUNTRIES

As the IPM approach provides a collection of management tools, rather than one method, IPM systems can be adapted to a wide range of climates, pests and facilities. IPM programmes of various kinds are used in food facilities from the humid tropics of Hawaii (Pierce 2000) to cool temperate areas of Scandinavia (Nielsen 2000). In the examples provided, there are many food processing and warehousing facilities using this approach to cost-effectively control many species of stored product pests without the use of MB (Stanbridge 2001).

## CONCLUSIONS

This control method is extremely effective and environmentally responsible. It can work for any facility but implementation needs to be done very carefully. A progressive attitude must exist within the facilities management team. The most difficult area of change is a philosophical one. It is human nature to resist change. Structures and equipment can be changed with money but attitudes can only be changed with motivation. The facility must be ready for change or this strategy will not succeed. This method will most surely succeed in facilities where there is motivation for an alternative to MB and a commitment from the highest level. This method has been proven to be a win–win option for a growing number of facilities because not only does it eliminate their need for MB but most often it also reduces their need for any other pesticide alternative.

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# METHYL BROMIDE ALTERNATIVES USED IN NORTHERN AND CENTRAL EUROPE FOR THE DISINFESTATION OF STRUCTURES

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## ABSTRACT

Pest control in mills is as old as the mills themselves, often going back more than 100 years. In response to the Montreal Protocol, many mills in Scandinavia banned the use of methyl bromide (MB) at least 5 years ago. Since that time, the millers have put in place sanitation methods to control pests, combined with a disinfestation treatment when necessary. $Eco_2Fume^®$ (phosphine + CO2 + heat) has been tested in Denmark and is expected to be registered in 2004. Sulfuryl fluoride has not yet been submitted for registration in Denmark although tests in more than 30 mills in Europe have been carried out successfully. So far more than 100 heat treatments have been carried out in mills in Europe. Sanitation applied as an Integrated Pest Management programme provides a sound and cost-effective foundation for pest control and, when properly applied, can completely avoid the need for a disinfestation treatment. The application of these treatments as alternatives to MB in mills in northern Europe are discussed.

## INTRODUCTION

The extermination of beetles, moths and other pests in mills and mill buildings is a tradition going back more than 100 years in Denmark. The mills and silos in northern Europe are typically very old structures constructed of brick and wood and themselves more than 100 years old. Some mills are disinfested every year usually once but sometimes twice (in the Spring and Autumn).

Methyl bromide (MB) has for many years been considered as the best fumigant for use in flour mills and other food processing structures. Compared to other fumigants, it is relatively inexpensive, easily applied, presents no fire hazard, leaves no harmful residues and is relatively quick-acting. Phosphine has never been considered as an alternative to MB in Denmark because of its corrosive properties to electrical equipment, although it has been used for spot fumigations together with residual insecticides.

A number of European countries have phased out the use of MB since its ozone depleting properties were first reported in 1991 (Table 1).

Table 1: Prohibitions and restrictions on the use of methyl bromide in countries in Europe

| Country | Decision | Tonnes used in the past |
|---|---|---|
| Denmark | Methyl Bromide banned 1 January 1998 | 33.3 |
| Finland | Banned 1 January 1999 | 6.5 |
| Germany | Permitted for post-harvest uses (including empty spaces, mills) until 31 September 2002. After this date, companies can use stocks until 30 September 2004 | < 100 |
| Italy | Permitted for critical use exemptions (160 t for 2005; 130 t for 2006) | 236 |
| Norway | Banned 1 January 2005 | 10.9 |
| Spain | Follows Regulation (EC) No 2037/2000 and use phosphine when possible | ------ |
| Sweden | Banned 31 December 1998 with some dispensations | 18.0 |

When considering alternatives to MB, the efficacy of MB was not subject to the same scrutiny as the alternatives themselves. How effective is MB? Is 100% pest mortality consistently achieved with MB? Are pest samples (bioassays) always included? Was the fumigation monitored from beginning to end? Most MB fumigators, in the interests of saving costs, do not include pest samples and monitor concentrations. Because of this, pest mortality is probably only 70-80%.

## COST OF METHYL BROMIDE TREATMENTS IN DANISH FLOUR MILLS

In order to gain an understanding of the price mill owners are willing to pay for a MB alternative, it is important to understand the costs of MB fumigation in the past.

Table 2: The cost of MB fumigation (in euro €) over 5 years in 3 Danish flour mills.

| ***Mill No 1 (100.000 tonnes of grain/y)*** | **1993** | **1994** | **1995** | **1996** | **1997** |
|---|---|---|---|---|---|
| No. of fumigations | 0 | 0 | 0 | 0 | 0 |
| No. of spot fumigations | 0 | 1 | 0 | 0 | 0 |
| | **€** | **€** | **€** | **€** | **€** |
| Cost of fumigations | 0 | 1,316 | 0 | 0 | 0 |
| *Cost of PCO ( IPM) | 5,372 | 5,372 | 5,372 | 5,372 | 5,372 |
| Cost of cleaning (staff) | 49,158 | 49,830 | 50,501 | 51,039 | 51,844 |
| Other costs | 5,775 | 5,910 | 6,581 | 6,447 | 6,313 |
| Total cost of pest control | 60,306 | 62,428 | 62,455 | 62,858 | 63,530 |

| ***Mill No 2 (85,000 tonnes of grain/y)*** | **1993** | **1994** | **1995** | **1996** | **1997** |
|---|---|---|---|---|---|
| No. of fumigations | 2 | 1 | 1 | 1 | 0 |
| No. of spot fumigations | 0 | 0 | 0 | 0 | 1 |
| | **€** | **€** | **€** | **€** | **€** |
| Cost of fumigations | 15,715 | 7,924 | 8,059 | 11,014 | 6,850 |
| *Cost of PCO ( IPM) | 5,372 | 5,372 | 5,372 | 5,775 | 6,044 |
| Cost of cleaning (staff) | 80,587 | 83,811 | 87,034 | 128,940 | 134,312 |
| Other costs | 507 | 761 | 1,014 | 1,268 | 1,420 |
| Total cost of pest control | 102,181 | 97,868 | 101,479 | 146,996 | 148,626 |

| ***Mill No 3 (150,000 tonnes of grain/y)*** | **1993** | **1994** | **1995** | **1996** | **1997** |
|---|---|---|---|---|---|
| No. of fumigations | 1 | 1 | 1 | 1 | 0 |
| No. of spot fumigations | 0 | 0 | 0 | 0 | 0 |
| | **€** | **€** | **€** | **€** | **€** |
| Cost of fumigations | 11,551 | 11,819 | 12,088 | 16,923 | 0 |
| *Cost of PCO ( IPM) | 5,372 | 5,372 | 5,372 | 6,716 | 7,119 |
| Cost of cleaning (staff) | 47,009 | 47,009 | 47,009 | 68,499 | 73,872 |
| Other costs | 1,612 | 1,612 | 1,746 | 2,552 | 3,492 |
| Total cost of pest control | 65,544 | 65,813 | 66,216 | 94,690 | 84,482 |

*Estimated figures

Since 1997 MB price has continued to increase which gives further opportunities for installing a suitable alternative.

The alternative to MB that is being tested is sulfuryl fluoride (SF, ProFume®), while $Eco_2$Fume® (phosphine, heat and $CO_2$) and Integrated Pest Management (IPM) have been used commercially. Both fumigation alternatives require bioassays and gas monitoring during treatment. The application and cost of these alternatives to MB are described.

## ALTERNATIVES TO METHYL BROMIDE FOR FLOUR MILLS

### Sulfuryl fluoride

DowAgroSciences has registered SF in Italy, Switzerland and the UK. Registration is under consideration in Germany (expected 2004), France (2005), Benelux (expected 2007), and Spain (expected 2007). Registration has not yet been sought in Sweden, Denmark, Norway and Finland.

SF rapidly penetrates porous materials, it has low sorption on fumigated materials, it rapidly aerates from structures, materials and commodities and it does not react with materials to form unpleasant odours. To date, more than 30 mills all over Europe have already been successfully fumigated with SF.

**Eco$_2$Fume**

Eco$_2$Fume® is a cylinderized phospine (2%) and $CO_2$ (98%). When combined with a heat treatment, Eco$_2$Fume® is an alternative to MB. Eco$_2$Fume has been used in the USA and Canada for several years and is expected to be registered in Denmark in 2004.

Eco$_2$Fume® in combination with heat and $CO_2$ was tested in June 2002 in a Danish flour mill. The target insect pests were *Tribolium confusum* and *Ephestia kuehniella*. The fumigation included the mill, packing area, warehouse and silo (flour) cleaning areas. The total volume was 45,000 $m^3$.

Before fumigation, the entire area was cleaned and all the machinery and production areas were opened up for gas access. Three CTU heaters (capacity 10,000 $m^3$/hour) were used to heat up the building before the fumigant was applied. They ducts from the heaters were disconnected immediately prior to fumigation. Inside the building, 12 CLA heaters were strategically placed to heat to the target temperature of 30 – $35^0$C.

In total, 50 bioassays with all stages of *T. confusum* were placed all over the mill for determining mortality. Twenty-two temperature probes located on all floors recorded temperatures and allowed provided feedback for heat control. Fans were placed throughout the mill to circulate the fumigant and heat. For corrosion control, electronic equipment such as computers were either removed or flushed with $CO_2$.

Eco$_2$Fume® was applied through copper hoses until the concentration reached about 100 ppm. The gas level was monitored by extracting samples. If the concentration was less than 100 ppm more gas was added. The fumigation was terminated after 48 hours.

The bioassays where taken out and observed for 3 months. No live insects where found and according to the miller this fumigation treatment was more effective than MB. With further experience the cost is expected to be no more than 40% more expensive than MB, based on 1998 prices.

**Integrated Pest Management in mills and other food facilities**

IPM, in combination with a planned and effective cleaning system, can be a good alternative to MB and fumigants in general. IPM is neither a treatment nor a patented solution, nor is it any special formula to keep away pests. It is a process, an attitude, a system which continually aims at keeping pest at acceptable levels. IPM involves all employees from the top level management to the people in the production line. IPM is like a puzzle and the following points must be considered when implementing an IPM system:

- A comprehensive knowledge of the site
- An assessment of potential risk
- Preventative proofing and control. Modification of plant and construction to remove regions of harborage
- Access to all areas, and detailed full site plans
- Knowledge of the material flow through the site
- Working practices and cleaning routines
- Future plans regarding new products, machinery or building alterations
- Clear lines of communication and responsibility
- Any agreements / contracts between the mill and an outside pest control contractor

- The number and limits of any hygiene inspections
- Communication at all levels of the hierarchy within the mill and with outside contractors
- Training of personnel in pest and stored product insects
- Documentation, the content and filing of all reports concerning integrated pest management.
- Quality control
- Testing new methods and assessing existing ones
- Contingency plans in case of an acute infestation

Major food plants over the world already have shown that they can control pests without the use of fumigants. As an example, a major international food plant in Denmark that specialises in cereals, showed in 1996 that over a period of two years it was possible to transition from two MB treatments per year to thorough cleaning and IPM. Another positive effect also showed that the use of traditional insecticides decreased simply due to very good inspections and cleaning methods, not only from services provided by a pest control service but also through the implementation of a very good in-house system, with quick reaction if problems with pests accrued.

**Heat Treatment**

Heat treatment is not a new technique. It has been used for many years all over the world and is widely used as an alternative to MB.

Small mills and relative modern mills (new buildings) can be treated successfully with heat. However, large, older mills with 80 cm brick walls and big wooden beams can be difficult as heating up the bricks absorbs a lot of energy. Conversely, the temperature inside the mills can rise to a temperature that can damage some of the equipment in the mill. The distribution of heat in old buildings with many floors and rooms (small and big) demands a suitably effective distribution system.

Heat can be effectively used but it needs to be carried out with the full cooperation of the mill managers and the company that carries out the treatment. With experience and trials the price can be reduced. European firms that specialise in heat treatment of food factories have carried out more than one hundred heat treatments.

## CONCLUSIONS

As MB will need to be phased out to protect the ozone layer it is feasible to return to the "old methods" like sanitation but with more efficiency such as those methods developed using IPM to give total quality control of pests.

IPM together with HACCP gives the food producers the possibility of being in control and using the right alternative or method for the given situation - this could be a fumigant, but also it could be less toxic products. Only the future will determine the most effective and suitable method for a individual food company. For sure, the more complex methods will demand more education and training.

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# THE USE OF CONTROLLED ATMOSPHERES AND HEAT FOR THE DISINFESTATION OF COMMODITIES, ARTEFACTS AND STRUCTURES

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## ABSTRACT

Insects and other pests in commodities, artefacts and structures need to be controlled to meet customer requirements. Methyl bromide and phosphine fumigants that have been widely used in the past as disinfestation agents have well-documented environmental and other problems. These problems have been overcome in the Netherlands through the commercialisation of controlled atmospheres, heat, and heated controlled atmospheres. These treatments that can be accommodated within the logistical requirements of many import products are safe, affordable, effective, residue-free, and environmentally-friendly alternatives to MB. Developed in the Netherlands, these treatments are now being replicated in other locations in Europe and elsewhere to meet the requirements for decentralised disinfestation of food and non-food items.

**Keywords**: Pest control, controlled atmospheres, heat, disinfestation, post harvest, environmentally-friendly, methyl bromide, phosphine

## INTRODUCTION

Insects and other pests contaminate and destroy food supplies and annually cause millions of dollars worth of damage to food, food storage and processing facilities, and historical artefacts. Pests in food in particular are considered a health risk and must be eradicated. Pests can also enter on packaging material such as wooden pallets leading to the accidental introduction of highly damaging quarantine pests which can become costly to eradicate.

There are a wide variety of measures that can be taken to manage the pests. Methyl bromide (MB) is ozone depleting and leaves residues in the treated product. Pests can also be controlled by phosphine but they are showing resistance to the fumigant. Phosphine requires relatively long treatment periods and, unlike MB and heat treatments, phosphine is not approved by the International Plant Protection Convention (IPPC) as a treatment for wooden packaging material.

The production of MB will drop by about 70% from 1 January 2005 due to the implementation of the international agreement under the Montreal Protocol to the phase out about 70% of the MB in developed countries. The phase out will affect uses that are not categorised as Quarantine and Pre-shipment (QPS) such as flour mill fumigation and immediate treatment of foodstuffs when imported to control non-quarantine pests.

Local regulations may also restrict the use of MB for postharvest use, even for QPS that is not restricted under the Montreal Protocol. For example, the European Union limits the amount of MB for QPS to 1,012 tonnes annually for all 25 Member States and, by agreement under the Management Committee operating under Article 18 of Regulation (EC) No 2037/2000, can reduce this amount in the light of the development of alternatives to MB for QPS. Therefore, as more alternatives are developed one could expect MB to become less available for QPS in the EU.

Some disinfestation treatments are carried out in shipping containers before export in order to control pests during transit. The number of containers that is fumigated with toxic chemicals is increasing (VROM 2004). These containers need to be vented on arrival in order to make them safe before unloading. Venting of fumigated containers is likely to be more restrictive in the future in order to minimise emissions harmful to the environment and worker safety.

Finally, QPS regulations are becoming increasingly complex. The IPPC operates internationally and has established guidelines for the development of disinfestation treatments. An example of a guideline is International Phytosanitary Standard Measure No.15 (ISPM-15) which allows the use of either heat or MB for the disinfestation of solid-wood packaging material (SWPM). An importing country can also establish national regulations that require the exporter to apply a disinfestation treatment prior to export in cases where the importer considers the imported product carries an unacceptable risk of pest contamination. Typically, the exports are treated with MB even when other treatments are available but clearly this is not sustainable in the long term with the reduction in the use of MB worldwide.

Importers and exporters are under intense pressure to find safe and effective alternatives to control insects in commodities, artefacts and structures that replace the use of MB and other toxic chemicals. This paper describes the commercialisation of controlled atmospheres (CA), heat, and heated-CA for the control of insect pests in a diverse range of food and non-food products.

## ALTERNATIVES

### Controlled Atmospheres

CA are based on the establishment of a low-oxygen environment which kills pests. $EcO_2$ BV is using CA to control all stages of insects, rats and mice in food, associated products, artefacts, silos, food (processing) facilities and barges.

The products are exposed to CA in airtight climate rooms equipped to handle variable sorts and quantities of products. The temperature, oxygen, carbon dioxide and humidity are controlled in each room within a specified range known to be toxic to the pest. The treatment requires 3 to 10 days, depending on the type and level of infestation, which is comparable to the time for some phosphine fumigations when both treatment and venting time are taken into consideration. The treatment is fully automated and can be initiated, monitored, managed and halted online by computer.

CA is also a highly effective treatment to control insects in artefacts of historical value as this treatment does not affect paper, paint, leather, textile, wood, metal, plastic, ink and varnish. The objects or products can be treated when packed. The level of humidity in particular must be closely monitored in order to comply with local cultural heritage regulations. The climate chambers are also suitable for the treatment of imported products or objects that might contain pests. Approximately 6,500 $m^3$ of artefacts and furniture were treated in 2003 in the Netherlands by $EcO_2$ BV.

Special service terminals containing the airtight climate rooms can be found throughout the Netherlands, Belgium and in Uganda. In addition, a fleet of mobile installations enables the same treatment with CA to be used in specific locations such as buildings, silos, barges and structures as both preventive and curative measures. The number of treatments in each year has been increasing as shown in Table 1 and Figure 1.

***Table 1:*** ***The use of heated controlled atmospheres for silos and vessels in the Netherlands***

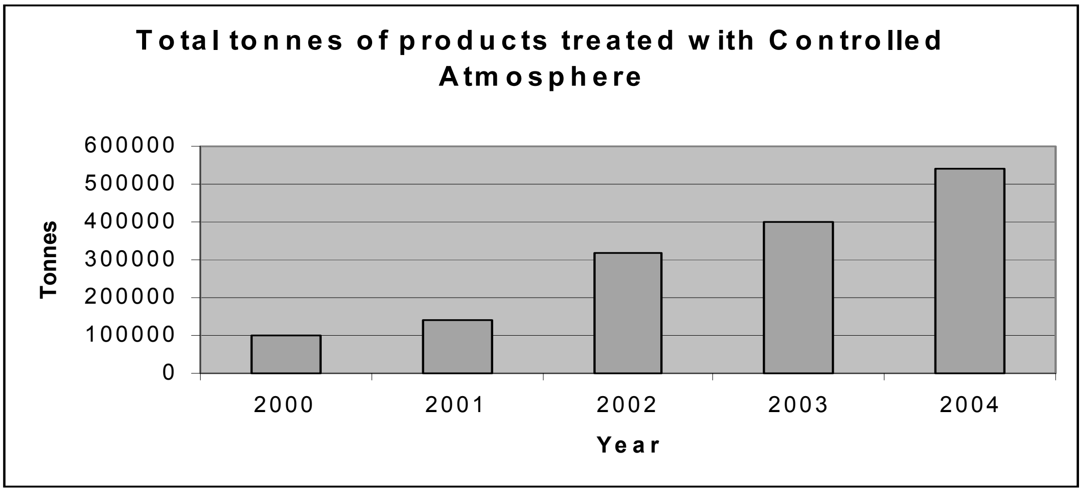
| | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|
| | | | | | |
| Silos | 2 | 10 | 11 | 16 | 24 |
| Vessels | 2 | 6 | 8 | 18 | 26 |

### Heat

Heat treatments consist of raising the temperature of the structure to at least 56°C for an average of 36 hours. It can be used to control all stages of insects in different types of buildings and structures, including historic buildings. Mobile heating equipment that also controls humidity is used to distribute heat as uniformly and as slowly as possible to avoid damage to the building. The mobile equipment is generally not expensive and the energy costs are modest.

In The Netherlands, heat treatments have replaced MB for disinfestation of flour mills and aircraft. During the period 2000 – 2003, $EcO_2$ BV used heat to disinfest 10 historic buildings and an historic windmill.

Figure 1: Commodities[23] treated with Controlled Atmosphere by by $EcO_2$.




Heat applied over a period 24 hours, in compliance with ISPM-15, is also an approved disinfestation treatment for the treatment of pallets, SWPM and dunnage. The same heat treatment can also control fungi on wet timber. Although heat requires investment in specialised facilities, it is a safe, non-toxic, environmental-friendly and effective substitute for MB. $EcO_2$ BV has disinfested approximately 68,000 $m^3$ of SWPM, pallets and dunnage since the introduction of ISPM-15 in June 2003.

**Heat combined with controlled atmospheres**

Heated-CA is now commercially available as "$EcO_2$ Quarantine and Pre-Shipment Treatment®" ("EcO2 QPS treatment") for controlling insects in a range of products. It is a proprietary system which is specifically developed for the treatment of containers, general cargo and big bags, containerised wooden pallets, packaging materials and dunnage. The treatment combines heat with low-oxygen and takes 24 hours. The temperature is controlled in strict compliance with ISPM-15 while the low-oxygen concentration protects the product from oxidation.

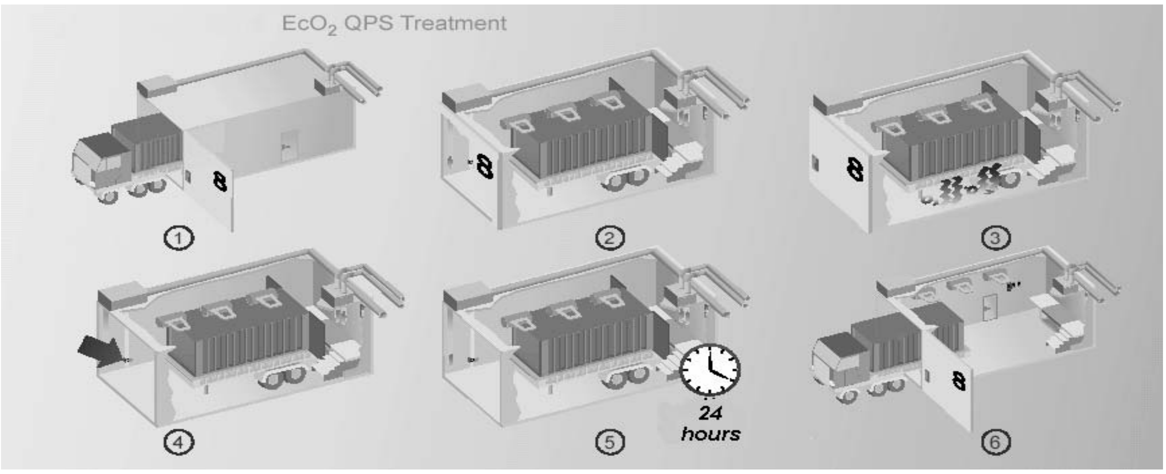
Commercially, "EcO2 QPS Treatment" is applied in service terminals or at container terminals where full containers, loaded with packaging materials together with the goods, can be treated together. Located in the Port of Rotterdam, the REST provides a total solution for the treatment of import and export containers. Containers treated with the "EcO2 QPS Treatment", or heat alone, are vented in a closed circuit in order to conserve heat and gas mixtures (Figure 2). The process runs automatically and toxic gases are filtered with the use of a sophisticated filter system in a fast and safe way.

$EcO_2$ BV estimates that approximately 3,500 containers will be treated with the QPS treatment in 2004. "EcO2 QPS Treatment" can handle more than 95% of all export containers (depending on the

[23] Note: the year 2004 is based on the first 6 months of the year. Treated products include: - Almond – Anise – Barley – Basmati rice – Brazil nut – Buckwheat – Cabbage seed – Cocoa beans – Cardi seed – Carob – Cashew nuts – Cereals – Chickpeas – Chinese kidney beans – Cinnamon – Clover seed – Coffee – Coriander – Dried apple – Dried apricots – Dried beans – Dried grapes – Dried peach – Dried pepper – Dried plums – Dried red pepper – Dried shrimps – Dried tomato – Dried white beans – Flour – food additive – Ginger – Grain – Grass seed – Grated coconut – Ground nuts – Ground pepper – Hazelnuts – Honeysuckle – Hibiscus leaves – Indian corn – Juniper berry – Lettuce seed – Mace – Maize – Maize groats – Marjoram – Millet – Mustard seed – Nutmeg – Nuts – Oats – Onion flakes – Onion powder – Onion seeds – Organic barley – Papua mace morsel – Peas – Pecan nuts – Perilla seed – Pet feed – Pig feed – Pinto beans – Pistachio nuts – Pumpkin kernel – Radish seed – Raisins – Rice – Seeds – Senna – Sesame seed – Sorghum – Soup additive – Soya beans – Soya germule – Spices – Sunflower seed – Tobacco – Thin grapes – Walnuts – White pepper powder – White sorghum and more.

heat sensitivity of the cargo). The treatment treated 77% of the containers that had to be fumigated in the Port of Rotterdam in January – June 2004 (Roteb 2004).

Figure 2: Schematic of the "$EcO_2$ QPS Treatment" that complies with the ISPM 15 norm ($EcO_2$, 2004)




**REDUCTIONS IN THE USE OF METHYL BROMIDE IN THE NETHERLANDS**

MB consumption in the Netherlands has decreased by 40% from 4,190 kg in 2001 to 2,552 in 2003 due to the implementation of MB alternatives. On the other hand, the use of MB for QPS in the Netherlands has increased from 1,200 kg in 2001 to 1,687 kg in 2003 (VROM 2004), mainly due to an increasing number of importing countries that require the EC to undertake a pre-shipment treatment for SWPM. This increase is primarily due to the world wide implementation of ISPM-15 and many other countries have reported similar increases (TEAP 2004). Heat treatment following ISPM-15 is one method to avoid the use of MB for this purpose.

**FUTURE AND CONCLUSIONS**

$EcO_2$ BV foresees a strong demand for environmentally-friendly pest control treatments as the trend continues toward even stricter regulations on the use of chemicals to control pests and increased consumer awareness aimed at minimising pesticides in the food chain. At the same time, importers are seeking pest control treatments that can be carried out quickly to meet just-in-time supply, and preferably treatments that require no prior authorisation to comply with national legislative requirements.

To meet these requirements, $EcO_2$ BV proposes a new concept to disinfest containers, commodities and artefacts in a closed circuit within a treatment terminal. A Multi Purpose Terminal (MPT) will be constructed that offers different treatments not only for export containers to meet QPS regulations but also for venting of import containers that have been gassed in transit with toxic chemicals.

The MPT will offer 1) QPS treatment with low-oxygen and high temperatures; 2) CA for commodities; 3) Heat for wooden packaging materials; 4) CA for containers; 5) MB and phosphine fumigation in conditioned areas with filters; and 6) safe degassing of containers.

CA, heat, and heated-CA are effective alternatives that are safe, affordable, effective, residue-free environmentally-friendly alternatives to MB. Infrastructural investment is required in other countries similar to that undertaken by the Netherlands in order to fully substitute MB.

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# THE ROLE OF ATTITUDES, ECONOMY AND TRAINING IN METHYL BROMIDE SUBSTITUTION: AN EXAMPLE FROM THE POST-HARVEST SECTOR

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## ABSTRACT

Poor analysis to determine the economic viability of an alternative to methyl bromide, and lack training of staff in pest control in flour mills, are the main obstacles limiting the rapid adoption of alternatives in the German flour mill industry. Economic considerations in deciding whether or not to adopt an alternative are less important when the marginal cost of the alternative treatment is added to the cost of the retail product. It becomes difficult to understand the reasons for developed countries requesting CUEs for the disinfestation of flour mill and food facilities when effective, economic, safe and cost effective alternatives are available. A model cost comparison is given in this paper to support this conclusion.

**Keywords:** Methyl bromide, alternatives, attitude, economy, post-harvest, training, critical use exemption

## INTRODUCTION

Currently, a considerable number of industry leaders who are managers in the food and feed industry, as well as pest control operators, have retained methyl bromide (MB) as the major tool for disinfestation of pests within their facilities. What are the real reasons for this? This paper examines possible thinking behind the selection of an alternative and proposes reasons for the lack of adoption of alternatives to MB by some mill operators.

## ATTITUDE TOWARD ALTERNATIVES – TECHNICAL AND ECONOMIC CONSIDERATIONS

### Attitudes

As trainers in the adoption of alternative pest control measures that have regular contact with industry decision makers, we are convinced that the most important obstacle to a broad, quick and smooth implementation of alternatives to MB as post-harvest treatments is primarily one of attitude toward the suitability of the alternative compared to MB, and the cost of the alternative. Two major attitudes prevail:

*Attitude # 1: Methyl bromide is the best treatment*

This view that MB is the best treatment cannot be scientifically justified. Technical aspects of the alternatives to methyl bromide used for disinfestation of commodities, structures and objects are now well understood and the results have been replicated in many different situations in the past decade (Bell *et al.* 1996, Bell *et al.* 1998, MBTOC 1994 and 2002).

The only logical conclusion from a review of these research programmes is sufficient alternatives to MB are available and they are capable of controlling pests in flour mills to the same or better standard than MB. Compared with MB, alternatives offer additional positive features such as lower toxicity, less environmental risks, lower residues in food and feed, better quality of produce and improved compliance with official regulations.

*Attitude # 2: Alternatives are expensive*

This view is not completely false because changes in methods of pest control require investment in equipment and material, in some cases greater workload, more supervision and documentation and certainly better training. And all of these tend to increase cost. Most often the consideration by the mill manager comes to a stop at this point, but it is worthwhile continuing with the calculation until the consumer's share of the burden is identified.

The conventional consideration of cost of methyl treatment against cost of an alternative follows more or less the example outlined below:

Assumption: The cost of MB fumigation in an average mill in Germany is about € 25,000. The cost of a viable alternative e.g. heat treatment combined with gaseous phosphine in low concentration, is about € 50,000. Furthermore, the alternative may require one more day of standstill of the mill. An average mill produces 500 t of flour/day with a market price of € 0.30 per bag of 1 kg (retail size). Thus the production of one day has a commercial value of € 150,000. The additional cost of the alternative is thus € 25,000 for the difference in price of the treatment plus € 150,000 for an additional day of standstill. This adds up to € 175,000. This total cost leads to the conclusion that the alternative is too expensive.

This conclusion is erroneous because the annual output of a mill in our example is 175,000 tonnes of flour, presuming that the mill works during 350 days with a production of 500 t/day, which is realistic. The total market value of the annual production is thus € 52.5 million. Compared to the annual output of 175 million 1 kg bags of flour, the additional cost on one bag caused by the alternative treatment would be € 0.001 or roughly 0.01 centimes per bag (1 hundredth of a centime per bag).

This does not seem to be a high amount to people in Europe who have been known to pay 3 centimes more per litre of fuel which is an increase three thousand times more than the increase per bag of flour. One assumes from this example that both fuel and flour are examples of 'elasticity in expenditure' since the consumer will continue to absorb such increases for essential services or products.

Thus, the real problem is definitely not the price of a treatment *per se* but rather the interaction between buyer-managers in supermarket chains/discounters who will only pay the absolute minimum price to the mill manager for flour so that the supermarket can remain competitive with other similar supermarkets. And the customer is taught by advertising campaigns that purchasing excessive amounts of food is praiseworthy. It is this kind of attitude and this approach towards food business that should come to an end in order to promote good and healthy food.

Recent investigations on consumer behaviour have painted a more optimistic picture. The results of these studies indicate that the consumer is willing to pay more for "healthy food" and health products than in the past. This change in attitude should be supported on all levels.

## TRAINING

Most of the technical staff in the food and feed industry is relatively poorly trained in pest prevention and monitoring techniques. The major reason given for lack of training is cost. However, training about 30 staff in a flour mill in a 3-day course per year would cost about € 60,000, the equivalent of € 0.0003 or 0.003 centimes per bag of flour. Who cannot afford this?

The price of not having trained staff in many cases can be much higher than the price of having trained staff. For example, tea coming from a supplying company was rejected because of Indianmeal moth infestation. In spite of otherwise relatively high standards of sanitation, the product remained untreated in the factory for several days before the infestation was detected. The cost of the disinfestation treatment for the entire facility would have far exceeded the cost of training staff in sanitation procedures that would have avoided moth-infested tea altogether. In this case, proper training in pest prevention and sanitation would have saved much more money than the training would have cost, thereby minimising the need for a MB or alternative treatment.

With regard to MB substitution for post-harvest applications in Germany, training of fumigators is a key component for success. This training is regulated by German Chemicals Legislation. Everybody who wants to become a fumigator must pass a five-day basic training course with an officially licensed training company, including a final examination at the presence of a government official. In addition, sufficient professional experience must be acquired, which includes an 18-month period of practical exercise under the supervision of an experienced fumigator. During this period, the applicant has to participate in at least four complete fumigations for every field in which he wants to become engaged such as fumigation of silo bins, warehouses, bag stacks, containers, etc.

The training course focuses on:

1. Characteristics and mode of action of the respective fumigant
2. Legal requirements
3. *Fumigants, modes of action and areas of fumigant application*
4. *Application techniques*
5. *Measuring gas concentration*
6. *Protective equipment*
7. *Toxicology and First Aid*
8. *Regulations concerning occupational health*
9. *Practical exercises*
10. *Repetition of essential topics and Q-A discussion*

Training courses should provide the knowledge necessary to execute state of the art fumigations. The courses should be practically oriented with exercises held in typical storage facilities. Apart from being introduced into the correct methods to apply fumigants, participants should be taught to identify pest and hygiene problems correctly, and to develop concepts that limit re-infestation. In addition to the compulsory topics, the courses should cover important areas such as stored product loss prevention and identification, biology and assessment of damage of major storage and quarantine pests as well as consideration of costs and discussions with end-users/customers.

The use of MB alternatives should be a permanent and important topic in our courses. Furthermore, training should include methods for pest prevention and monitoring, food and feed security and hygiene, and fumigation-degassing of sea containers which is an important issue in the QPS sub-sector. Such courses will facilitate the implementation of sound MB alternatives in Germany.

## CONCLUSIONS

It becomes difficult to understand the reasons for developed countries requesting critical use exemptions (CUEs) for the disinfestation of flour mill and food facilities when effective, safe and cost effective alternatives are available.

Within our experience, there is no real problem in Germany for the food, feed, milling and storage industry that could not be easily solved by implementation of proven alternatives. It would appear that obtaining a CUE is the cheapest way for some managers in the short term. Companies which have developed approved MB alternatives are punished by this situation. State authorities should very carefully observe the scene. They have means to do so.

Some training organisations have started without public funding. However, government assistance to train inspectors should be provided by the European Union and/or Member States. Relevant information should also be channelled to consumer associations to raise the awareness of the MB problem with the public and to convince stakeholders of the need of MB alternatives. Consumers have considerable power if they exert it wisely.

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# CASE STUDY: THE USE OF CONTROLLED ATMOSPHERE FOR PEST CONTROL IN LASSIE RICE STORAGE FACILITIES (A SARA LEE COMPANY)

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## ABSTRACT

All stages of moth and weevil pests in rice in a ship hold are killed using a controlled atmosphere CA) for 10 days at 30°C. The CA treatment consists of a combination of less than 2% oxygen with the balance nitrogen and carbon dioxide. CA leaves no residues, is safe to use on a ship, and is a cost-effective treatment that has replaced MB. The treatment applied prior to the rice entering the factory avoids cross-contamination of infested with packed product, and mimimises the risk of consumer complaints of insect contamination.

**Key words**: Controlled atmosphere, methyl bromide, rice, stored product pests, alternative

## INTRODUCTION

Insect contamination of durable commodities is a worldwide problem that is normally resolved by a methyl bromide (MB) or phosphine treatment. Rice is one of the most common products that is shipped internationally and is susceptible to infestation by a range of stored product pests. The pests commonly found in rice imported into the European Union are the rice weevil (*Sitophilus oryzae*), flour weevil (*Tribolium confusum*) and flour moths (*Ephestia kuehniella*).

From 1994 until 1998, every shipment of rice on the barge received an MB treatment. As from 1998 until 2000 Lassie Rice carried out preventive examinations on insects in each cargo in the Port of Rotterdam. When pests were found a MB treatment was carried out. However, since 2003 time, Lassie Rice has used controlled atmosphere (CA) treatment as a replacement for MB for each shipment arriving at the port. Shipment at the port has avoided contamination in the factory where in the past disinfestation treatments had to be carried out.

The advantages of a CA treatment compared to chemical fumigation is that CA is friendly for the environment and safe for people, effective against all insects in every stage of life, requires minimal ventilation time and causes no problems with chemical residues.

## THE COMPANY

Lassie Rice is a Sara Lee company and part of Sara Lee DE Netherlands, Coffee & Tea Business. It's the only rice-factory in the Sara Lee organisation. Lassie Rice produces around 40 million consumer units a year and is market leader of the Dutch rice market.

Lassie Rice produces for the Dutch market short cooking brown and white rice, "Nut rice", "More Grain rice", Basmati rice, Pandan rice, different risotto's, couscous, and yellow rice. Lassie Rice also produces private label rice products for the Dutch market. Lassie Rice has a pre-cooking plant where brown and white rice get a pre-cooking process which results in short-cooking rice.

### Problems with insects

The problems Lassie Rice has with insects are the following:

- Contamination of cargo rice with insects like rice weevil (*Sitophilus oryzae*), flour weevil (*Tribolium confusum*) and flour moths (*Ephestia kuehniella*)
- Cross contamination with finished products in the factory
- Consumer complaints about insects in the product which must be minimized

- In the summer occur more problems with insects. In the winter period there are no problems.

**Formerly used solutions to prevent contamination with insects**

About 10 years ago al the cargo rice received an MB treatment before unloading in the factory. This was an effective method to kill all the insects in the cargo in every stage of life and it minimized a possible infestation of the factory. When it became clear that the use of MB to control insects in commodities would be prohibited in the Netherlands as from 2005, Lassie Rice was forced to search for possible alternative pest control techniques to replace it.

Lassie Rice also realized MB has several disadvantages such as it is:

- Bad for the ozone layer
- Dangerous for people near the cargo
- Requires a long ventilation time before cargo can be unloaded

Lassie Rice also investigated phosphine as an alternative. However, phosphine has the following disadvantages:

- Some insects are resistant to it
- It requires a long ventilation time before the cargo can be unloaded
- It is dangerous for people near the cargo

It was thus not only necessary to search for an alternative to MB or phosphine but also to look for an alternative to overcome the negative aspects of chemical treatments.

**Controlled Atmosphere**

In 1998, Lassie Rice had the first experiments with CA as alternative treatment. These tests were very positive and as from 2000 Lassie Rice only worked with the CA treatments for the control of insects in our cargo vessels. Together with a Dutch company (Eco2) a suitable treatment for the cargo-rice was developed.

The treatment with CA is a low-oxygen treatment which is a combination of $O_2$, $N_2$ and $CO_2$. With this treatment the $O_2$-content of the cargo is decreased to < 2% so that all the insects, larvae and eggs are eradicated. The treatment is effective at a temperature of 15$^oC$ degrees and higher. At an optimum temperature of 30°C the treatment takes 10 days.

The cost of the treatment is about € 10,- per 1000kg in a cargoboat and € 50,- per 1000kg in big bag or container.

In 2001 and 2002, Lassie Rice had an increasing number of infections with insects in the factory
In this period some CA treatments in silos in the factory were also carried out. Lassie Rice stopped the CA treatments in the factory because:

- It was dangerous for workers in production areas because of the low $O_2$ in the silos
- There were problems with condensation in the silos (ventilation after the treatment is very important to prevent condensation).

From Spring 2003 it was decided to treat all cargo vessels in the summer period with a preventive and curative CA treatment to minimize the risks of an infestation in the factory and/or consumer products. After the routine use of the CA treatment on the ship cargo, no infestations occurred in the cargo or in the factory. The CA treatment has therefore replaced MB with a cost-effective, long term, environmentally-acceptable pest control measure.

# TRANSPORTABLE HERMETIC STORAGE AND VACUUM EQUIPMENT FOR DISINFESTATION OF DURABLE COMMODITIES

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## ABSTRACT

Two technologies based on flexible PVC liners that enclose and seal the commodity are commercial alternatives to methyl bromide (MB). The first involves applying a pressure of 50±5 mm Hg to moth-infested soybeans held for 5 days at 20-30°C in GrainPro cocoons. In the second, the respiration of narcissus bulbs stored in GrainPro cocoons is used to generate an hypoxic atmosphere sufficient to kill pests within 48 hours at 30°C. Equipment, monitoring and handling procedures result in less cost than MB fumigation when amortised over 1-3 years, depending on the commodity and market. Both these treatments are therefore viable commercial replacements for MB.

**Keywords:** Quarantine, flexible liners, sealed storage, vacuum, soybeans, narcissus bulbs, pre-shipment.

## INTRODUCTION

The UNEP Methyl Bromide Technical Options Committee provides a detailed list of MB alternatives for the treatment of durable products and structures developed by various research groups. This list aims to assist developed countries to meet the Montreal Protocol's 1 January 2005 deadline for the phase out of MB. However, the list provided is far from comprehensive, and in particular there is an absence of treatments that could be used as substitutes for MB in quarantine treatments.

Critical use nominations (CUNs) have been submitted to the Technology and Evaluations Panel for the years 2005 and 2006, but even where these exemptions (CUE) have been agreed by the Parties to the Montreal Protocol, they are temporary and nominations must be renewed on an annual basis with decreasing likelihood that they will be received favorably.

Agricultural producers and food manufacturers recognise the urgent need to find MB alternatives in order to be able to continue trading. In Israel, where a major part of agricultural production is destined to the EU community, the critical stage of the MB phase-out has led Israeli researchers, in cooperation with local agricultural and food manufacturing industries, to take steps to maintain their obligations and conform with international regulations.

Consequently, three alternative technologies for treatment of durable commodities have been developed recently and introduced commercially this year. These are: heat treatments for fresh dates (not reported on here), and modified atmospheres (MAs) either by hermetic sealing or by the use of low pressures. In contrast to MB fumigation, which provides an across-the-board solution, each of the new technologies addresses a specific type of commodity according to the unique needs and limitations dictated by the commodity.

This paper addresses in particular the application of MAs with respect to their use for quarantine purposes, where until now the search for rapidly acting alternatives to MB has proved to be a major stumbling block. These alternatives have been evaluated both on the basis of their insecticidal effectiveness and their cost-efficiency.

To implement the two types of treatment under MAs we used flexible PVC chambers known as GrainPro™ cocoons that were developed in the past for hermetic storage of grain (Navarro *et al.* 1998) A great advantage of these versatile structures is that they can be modified to different sizes and dimensions, or tailor made for multiple uses by means of the addition of accessories.

In order to demonstrate the usefulness of these alternatives we present two commercial examples from the local agricultural and food processing industries.

## DURABLE COMMODITIES STORED AND HANDLED IN BAGS ON PALLETS

We have shown previously that low pressure applied to stacked bags provides excellent control of insects in granular (such as cereal grains, pulses, oil seeds, nuts, cacao and coffee beans) and farinaceous food products (Finkelman *at al.* 2003b).

In the past, a low pressure treatment was not feasible commercially because of the mechanical requirements for rigid and expensive structures capable of withstanding the very low pressures required to kill stored product insects. However, the GrainPro cocoons that were sufficiently gastight for hermetic storage were found to also withstand internal pressures of 25 mm Hg or less. At these pressures, most rigid structures would implode. However, a vacuum applied to the cocoons causes the volume to shrink until the flexible liner takes the shape of the stack of bags. This phenomenon can be seen in shrink wrapped retail packages, though pressures in the latter case are much higher. Consequently the liner retains its integrity and holds the vacuum.

We have already conducted studies on the effect of low pressures on the mortality of 6 important storage insects under uniform treatment conditions of 50 ± 5 mm Hg at 30°C and relative humidity of 55%. The pests were *Trogoderma granarium* (Everts), *Lasioderma serricorne* (F.), *Oryzaephilus surinamensis* (L.), *Tribolium castaneum* (Herbst) *Ephestia cautella* (Walker), and *Plodia interpunctella* (Hübner). In all these species the egg was found to be the most resistant stage. The longest exposure required to obtain 99% mortality was 91 h, for *L. serricorne* (Finkelman *et al.* 2004a, b). These studies, although not comprehensive, have been sufficient to consider an exposure time of 5 days (with a 25% safety factor) sufficient for control of insects where *L. serricorne* is suspected of being present, or considerably shorter whe other pests are present but *L. serricorne* is known to be absent.

The initial commercial scale trials were carried out on cocoa beans in Boston USA, with follow-up trials in Israel (Navarro *at al.* 2001). The different conditions of cocoa bean storage in the Ivory Coast, West Africa were then investigated (Finkelman *at al.* 2002b). This was then followed by a series of commercial scale trials in Israel that investigated vacuum treatments on almonds, garden peas, chick peas, sunflower seeds, rice, semolina, oat, corn chips and wheat flour. The exposure period was 5 days and pressure range of 50 ± 5 mm Hg (Finkelman 2003b).

The results of this research has now been commercialised in a comprehensive way in order to solve a specific problem in the food industry. Infestations of the tropical warehouse moth *Ephestia cautella* were found in imported soybeans destined for the milk substitute industry. Infestations were first discovered inside shipping containers holding the bagged commodity when opened at the factory. The infestation consisted of all stages of the insect. In evidence were also considerable contamination by larval frass and webbing.

As a result of this infestation the factory was closed down for a week until a new shipment arrived. A request was made to our laboratory to find ways to prevent future damage. Because of the MB phase-out we suggested two possible options to the factory, namely phosphine fumigation or low pressure treatment. Under local ambient conditions, control of *E. cautella* with phosphine would require a factory hold-up period of 5 to 7 days exposure (according to manufacturers' labels) followed by 1 day ventilation. Using low pressure, control of *E. cautella* would require 3 days (at 30ºC the LD99 is 42 h). However, we encountered temperatures in the imported soybeans of about 20ºC for which a treatment time of 7 days is required (based on LD99 at 18ºC of 149 h; Finkelman *et al.* 2003a).

Upon agreement with the factory management a Pest Control Operator (PCO) undertook the first low pressure treatment of the infested consignments, and these served also as a demonstration platform. Following these demonstrations the following procedure was adopted as routine: The supplier was authorised to insert pheromone traps into the shipping containers. Upon arrival at the Israeli port, an evaluation of insect infestation based on trap catch is made which serves to resolve ‘acceptance’ or ‘rejection’ of the consignment. If no insects are seen in the traps, the container is ‘accepted’ and transported to the factory for disinfestations in the "**V**acuum **H**ermetic **F**umigation" (V-HF) unit. After treatment the commodity is stored in a cold room to prevent re-infestation until processing. If no space remains in the cold room, the commodity is held in the V-HF unit, also to prevent re-infestation.

Technical specifications on the V-HF units have been described elsewhere (Finkelman 2002a, b) and can be obtained from Grainpro, Inc.[24] and Eitan Amichai[25]. In this case, the capacities of the flexible chambers were tailored to accommodate consignment volume.

**Cost analysis**

The full price of a V-HF unit including pump, control unit and the cocoon for 20 tons of soybeans is € 6580. The fixed (handling and operational) costs for one treatment are € 18. Therefore if the system is used once a week the fixed cost of one treatment (on an annual basis) is € 155 and, taking into account depreciation over the 10 year life guarantee, the final cost is only € 32 per treatment. The alternative of using phosphine to fumigate 20 tonnes of soybeans today in Israel is € 112 per treatment. Therefore after 70 phosphine fumigations the full investment of the V-HF unit will be recovered and the cost for any additional treatment will be € 18. Since the pump can be connected to more then one cocoon the investment cost of the system can be even lower.

**THE USE OF MODIFIED ATMOSPHERES BY BIO-GENERATION**

A number of durable products such as bulbs tubers and corms are marketed and stored while still respiring at a relatively high metabolic level. The disinfestations treatment described takes advantage of this aerobic metabolism to generate a modified atmosphere to kill any insects infesting the product.

Up till two years ago geophyte growers in Israel, fumigated with MB against the large narcissus fly *Merodon eques* F. to comply with quarantine regulations. Following customer complaints related to the phytotoxic effect of MB and aware of its impending phase out, the growers requested a solution that required the use of alternatives to MB. The alternatives proposed were: immersion in water with Diazinon™ insecticide, a low pressure treatment, hermetic sealing, high carbon dioxide, and propylene oxide (PPO).

All methods were found to be efficacious:

- PPO required the shortest exposure time but this gas is as phytotoxic as MB and the farmers were reluctant to substitute one toxic chemical with another;
- High $CO_2$ and low pressure were effective but both required special adaptations to the sealed system;
- Insecticide immersion requires additional handling procedures and the bulbs must be dried after treatment. Additionally, insecticide disposal creates an environmental hazard liable to government regulation; and
- Hermetic sealing was judged the most appropriate alternative. The commodity itself produces the low oxygen atmosphere to kill the pests without any additional inputs. Also the treatment has no adverse effect on bulb vitality.

The following procedure was adopted: After the bulbs are sorted in the packing houses, they are inserted into the V-HF units in their original shipping containers. Normally the temperature of the bulbs is about 30ºC but in order to maintain a satisfactory elevated temperature and bulb respiration rate, a fan circulating hot air within the chamber was inserted.

Today the growers operate six units at their packing stations. Results from the first year showed that after 48 hours the oxygen levels drop below 1% and then the bulbs stay for an additional 5 days under the hermetic seal. Pre-shipment inspection showed total insect mortality inside the bulbs and all consignments were approved for export.

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[25] Eitan Amichai, www.pest.co.il

**Cost analysis**

In the past, the fixed costs paid to the PCO for MB treatment were € 5.8/tonne and about 1,070 tonnes were exported annually. Therefore, the total annual fumigation costs were € 6,240.
The price of each cocoon is about € 2,200 and in order to accommodate the whole season the growers purchased 6 units. For depreciation, the units have a 10 year lifetime, implying an annual investment of about € 200 per unit.

Due to the decision of the growers to replace MB with the hermetic technology they no longer require the services of the PCOs. The growers will have recuperated their expenses in three years of use with no more expenses on future treatments. In this evaluation, the costs were excluded for the fumigation bubbles, applicators and monitoring equipment needed for the MB fumigations and purchased by the growers.

Further technical details of the field and laboratory trials may be found in Finkelman 2003 and in Rindner 2003.

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# INTEGRATED STORED PRODUCT PROTECTION METHODS TO REPLACE THE USE OF METHYL BROMIDE FOR PEST CONTROL IN GRAINS, DRIED FRUITS AND NUTS

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## ABSTRACT
The world-wide phase out of MB (MB) due to its ozone depleting potential requires new solutions in integrated stored product protection. There is no replacement available that equals MB in its broad biocidal effect while being comparably fast in action and cheap. In Germany, however, MB was registered in 1992 only for structural treatments. Grains (g), legumes (l), spices (s), dried fruits (f) and nuts (n) have instead been disinfested by one of the following means: phosphine fumigation (g, l, s, f, n); carbon dioxide ($CO_2$) fumigation (g, l, s, f, n); treatment with $CO_2$ under high pressure (s, f, n), freezing with liquid air or liquid nitrogen ($N_2$) (s, f, n); and application of pirimiphos-methyl (g). During the last decade, other techniques, such as biological control with parasitic wasps or the treatment of grain with diatomaceous earth have become available. This paper describes MB alternatives available in Germany and points out steps in product handling and processing that could be used for effective disinfestation. The decision to replace MB with alternatives appears to be political rather than technical.

**Key words**: Phosphine, carbon dioxide, high-pressure $CO_2$, biological control, diatomaceous earth, integrated stored product protection, IPM, structures, drying, cleaning, freezing.

## INTRODUCTION
Grain and legumes are important staple crops for human nutrition while spices, dried fruits and nuts are considered high-value stored products. Germany produces, exports and imports grain and legumes, but mainly imports spices, dried fruits and nuts. In 2001, almoust 50 million tonnes of grain were harvested in Germany, while in 2002 and 2003 harvests were reduced due to flooding or drought, respectively. In 2002, some 432,000 t of dried fruits and nuts were imported into Germany with a value of €1.015 billion. About 66,400 t (€176 million) of spices were imported to Germany in 2002 (source: Statistisches Bundesamt). Hamburg and Rotterdam (in the Netherlands) are the most important sea ports in Central Europe. From here, large quantities of products are shipped to other countries.

MB is a fumigant that combines short treatment times, high biocidal efficacy and low cost. It has been used for pest control and as a standard tool for pre-shipment disinfestation. Until recently, many importers have required goods to be fumigated with MB prior to shipment in order to secure pest-free import to destination. However, MB will no longer be available for most of its uses as it has a high ozone-depleting potential and the governments to the Montreal Protocol agreed to phase out its production and use.

The paper summarises MB alternatives used in stored products for protecting grain, legumes, spices, dried fruits and nuts. It is notable that MB was not registered in Germany for stored product protection of these products since 1992 and therefore Germany has relied on non-MB treatments for control. MB is currently only registered and used for structural fumigation such as for empty flour mills.

In developing alternatives to MB, Germany has developed integrated stored product protection which consists of methods to 1) Prevent stored product pests; 2) Detect pests as soon as possible in case prevention methods were not successful; and 3) Control pests by physical, biological, biotechnical and chemical means (summarised in Fig. 1). A loss in pest control should be augmented by efforts in pest prevention and early pest detection. First sites of storage that are sealed against pest entry are perhaps the most valuable in reducing the need for further 'downstream' pest control measures.

Moreover, each storage and production process should be analysed for steps possibly leading to insect control. Often these steps may just need minor modifications to become effective tools for pest control. Re-infestation needs to be prevented subsequently by physically separating treated from untreated products. Hermetic or at least insect-proof structures should be used for storage from farm to fork, and especially on-farm storages should be improved. Trade needs to improve methods for product quality audits and inspection at the suppliers level to reduce shipment of infested products and the necessity of pest control measures.

Product handling and structures in the processing industry need to be analysed according to Hazard Analysis and Critical Control Point Procedures (HACCP) in order to define procedures that reduce pest infestation risk. It is obvious that all methods available for pest prevention, pest detection and pest control should be applied in a way optimised for each product in order to fully exploit the chances of integrated stored product protection for the benefit of product quality.

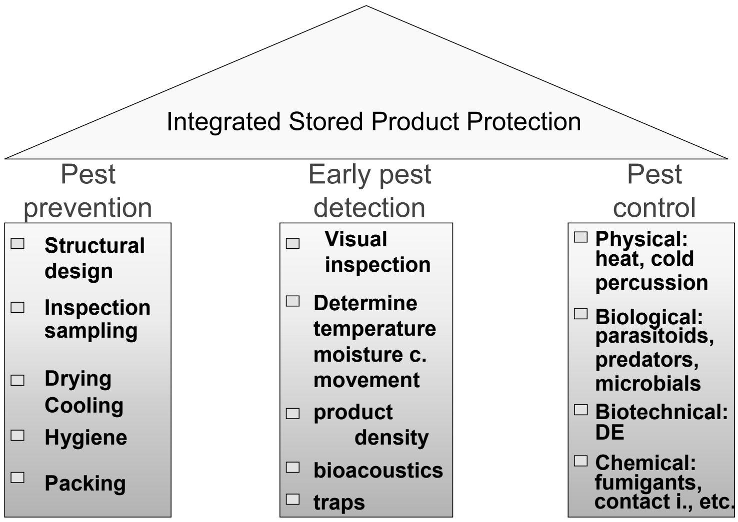


*Figure 1 The three columns of integrated stored product protection (modified from Adler 1996)*

Some examples of different methods are given for controlling pests in grain, dried fruits and spices.

## PEST CONTROL ALTERNATIVES

### Fumigation with phosphine

Phosphine has been used as a fumigant in Germany since the early 1940s. While for more than 50 years, phosphine has been developed from metal phosphides such as aluminium phosphide or magnesium phosphide, bottled phoshine gas is now available. In bottled phosphine the problem of flammability of higher concentrations of this gas is overcome by admixing carbon dioxide (Insects Ltd., USA), nitrogen (S&A,Germany) or pressurised air (Horn, Chile).

At 20°C, the fumigation of a grain with phosphine derived from aluminium phosphide takes about one week compared to 4 days for bottled phosphine or 48h for MB. However, the trade in Germany and many other countries have adjusted to the longer treatment times. Phosphine fumigations have been used for pest control in all types of grain, legumes, dried fruits, nuts and spices. Progress in phosphine research is frequently reported at the International Working Conference on Stored-Product Protection and the series of conferences mentioned below.

Phosphine-tolerant or resistant strains of stored product insects have emerged in many parts of the world due to poor fumigation practices – doses sub-lethal to the pest caused by insufficient fumigant, short exposure times, insufficient gas tightness and often a combination of these factors. Good fumigation practices need to be urgently defined and implemented in order to retain the global use of phosphine. In addition, proper in-transit fumigation practices need to be developed and implemented to allow the safe use of phosphine on sea-going vessels. Other structural fumigants could include hydrogen cyanide or in the near future sulfuryl fluoride.

**Fumigation with carbon dioxide or nitrogen**

The disinfestation of stored products with carbon dioxide and/or nitrogen at ambient pressures has received considerable international attention since the 1980s, a fact reflecting in the international conferences on Controlled Atmospheres and Fumigation (CAF) held every four years. In Germany, $CO_2$ is used in goods from organic production or in highly gas-tight structures such as modern concrete silos, welded steel silo bins or silos made of fibre glass. Because the air is largely replaced by $CO_2$ and $N_2$, gas tightness needs to be considerably better than with phosphine. Treatment times for disinfestation are often longer than with phosphine, but work can continue around treated structures. A comprehensive overview on modified and controlled atmospheres can be found in Adler *et al.* (2000). Further chapters of this book describe other alternatives in stored product IPM.

**Fumigation with carbon dioxide at high pressures**

If $CO_2$ is used at pressures between 10 and 30 bars disinfestation can be carried out within minutes to a few hours, depending on pest species, pressure, temperature, product type, and the speed of pressure release at the end of the treatment. The treatment has to be carried out in special high pressure cylinders. Cylinders with a volume of up to some 20 $m^3$ are used in Germany for commercial disinfestation. Twin chambers allow the recycling of some of the carbon dioxide used which makes this technique more economical. Because the high-pressure chambers are quite expensive the treatment with $CO_2$ is used mainly for high-value products such as spices, herbs and drugs, dried fruits, and nuts. The treatment times are even shorter than with MB. Thus, where immediate and rapid disinfestation is needed such as when a product is first imported this technique may be useful even for grains or legumes.

**Treatment with diatomaceous earth**

Diatomateous earth (DE) has been registered in Germany for the treatment of grain since 1996. It can be used for pest control storage facilities and food premises. DE is an abrasive compound which is chemically inert. Once DE adheres to the surface of the insect it removes some of the wax layer in the insect cuticle leading to uncontrolled water loss which is regarded as the main cause of mortality. DE also interferes with insect movement, feeding and mating.

**Treatment with pirimiphos-methyl**

Pirimiphos-methyl is the only contact insecticide available in Germany for the treatment of grain that cannot be fumigated or treated with DE. It is mainly used in on-farm grain storages that are not sufficiently gas tight and can only be applied onto moving grain. The efficacy against internal grain pests such as *Sitophilus* species, *Rhyzopertha dominica*, or *Sitotroga cerealella* is limited, but it is also used as a structural treatment prior to storage of new products. In Germany, grain can only be treated once with this liquid insecticide if residues are not to surpass maximum permitted residue levels.

**Biological control**

Low levels of infestation can be controlled by an inundative release of mass-reared parasitoids or predators. In Germany, parasitoids against stored product moths are commercially available. These parasitoids are small wasps that lay their eggs in or onto juvenile stages of stored product pests. *Trichogramma evanescens* is a minute egg parasitoid invisible to the naked eye. This braconid wasp walks over surfaces randomly searching for insect eggs and is used for the protection of packed goods. Due to the fact that it hardly ever flies, *Trichogramma* can also be utilised in food industry and kept away from sensitive production processes by an adhesive tape. *Habrobracon hebetor* is a larval parasitoid of stored product moths killing its pyralid host during the process of its development. And *Venturia canescens* is another wasp attacking both larvae and pupae of stored product moths. Lariophagus distinguendus is another species attacking larvae of internal pests such as *Sitophilus* species and *Stegobium paniceum*. Details on the development in Germany were published by Schöller in Zdarkova *et al.* (2002). *Cheyletus eruditus* is a predatory spider mite feeding on the eggs of stored product insects, as well as mites.

All these biological agents may occur during a natural infestation, but can be utilised for effective pest reduction and to prevent a gradation if released in high numbers. Biological control should, however, be regarded as a method that helps to prevent pest increase rather than a tool to control severe infestations.

### Freezing

Freezing of products to temperatures of minus 18°C or below is a physical method like percussion or heating that does not require authorisation as a stored product protection method. Freezing has been used for high-value goods such as spices, medical herbs and drugs, dried fruits and nuts.

## IMPLEMENTING PROCESSING STEPS AND IMPROVED STRUCTURES

### Grain

Until recently, a modest level of infestation was often regarded as a natural law in the grain trade. A small survey of 47 grain samples from German grain storages in 1988 revealed that about one third of the grain stored as intervention grain was actually infested (Adler in Zdarkova *et al.* 2002). Supposedly, a first infestation often occurs already at the farmer's level where more effort should be made to prevent pest infestation.

Grain is harvested, threshed and moved into storage, processes that could effectively be used for insect control. The main factors leading to insect mortality here are grain movement and percussion. Thus, these processes need to be optimised in order to secure complete disinfestation as well as a minimum of kernel breakage. To the author's knowledge, the aspect of pest control has not yet been addressed by the manufacturers of combined harvesters, aspirators, or pneumatic conveyors. The function of these units could possibly be modified to act like a percussion unit for pest control.

Grain drying could be another method for pest control provided that temperatures reach 55°C for some minutes or 60°C for some seconds.

Most importantly, the immigration of pests should be prevented using closed transportation systems and hermetic storage structures. While concrete storage units and welded steel silo bins are available, wooden structures and more or less open sheds are still quite common on farms. Given the fact that in moderate climates most stored product insects do not occur in the field, immigration of pests from an infested environment into an unsealed storage structure, or from insufficiently cleaned storage sites, are probably the most important pathways leading to an infestation of the new harvest each year.

An hermetic, or at least insect-proof transportation and storage system, beginning at the farmer's level could considerably reduce infestation problems in the grain trade and food industry. The European guideline 178/2002 requires that all food items must be traceable back to the farm where they were produced. Thus, a closer supervision and customer audits by grain buyers and food industry inspectors could be an incentive to farmers to invest in insect-proof or even hermetic storages. Sealed storages prevent the emission of attractive volatile cues and thus do not attract stored product insects. Better supervision down the chain of grain processing could be an incentive for improved sanitation and grain product cooling or structural treatments, thus reducing the need of pest control measures. Moreover, this would also help to improve product quality as uninfested grain is preferred to that which needs to be disinfested.

### Dried fruits and spices

Many fruits and spices are dried to become durable. Drying can be carried out as solar drying in the open or in artificial dryers. In 2001, raisins from Crete were heated to 100°C to complete the natural drying process, a procedure that is more than sufficient to control all pests present. However, re-infestation was implemented and pre-shipment fumigation with MB was required as standard procedure before the raisins could be exported to Germany and elsewhere. Simple solar panels could be used to achieve a minimum of 60°C combined with procedures to prevent re-infestation afterwards.

## CONCLUSIONS

If an old method is simple, cheap and works well, keep it! Colombia gave up the use of MB in 1997, Venezuela stopped the use of MB at the end of 1999. Almost five years later, Europe is considering the elimination of MB. Given all the alternatives already documented in sufficient detail, the phase out of MB is becoming more of a political than a scientific issue.

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# DISINFESTATION OF CHESTNUTS WITHOUT THE USE OF METHYL BROMIDE

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## ABSTRACT

Chestnuts are the third largest crop grown in Portugal after grapes and olives. After 1992, the demand for Portuguese chestnuts doubled. Chestnuts are shipped from Portugal to other Member States and also exported from the European Community. No pre-harvest pesticides are registered. Pre-shipment treatment with methyl bromide (MB) is carried out at 48-50 $gm^{-3}$ for 24 hours at ambient temperatures (0-16°C) to control *Cydia splendana* Hubner and *Balaninus (Curculio) elephas* Gyll. The paper summarises the research in Japan that screened potential alternatives to MB for use on chestnuts. In Portugal, a hot water/steam treatment was implemented in two facilities to replace pre-shipment treatment with MB.

## PRODUCTION AND TRADING

Chestnuts are the third largest crop grown in Portugal after grapes and olives. Chestnuts are produced on about 25,000 ha of orchards. The national production of chestnuts in 2002 was around 35,000 tonnes per year. The importers in the previous decade were mainly Spain, France and Brazil. After 1992, the demand for shipments from other European countries increased considerably in most cases, while the demand for chestnuts from Portugal by countries outside the European Community stabilized. Table 1 shows these trends as an example from the Trás-os-Montes region in Portugal.

Table 1: Shipments of chestnuts to other EC countries and exports of chestnuts from the Trás-os-Montes region in Portugal

| Country of destination | 1992 | 2002 |
|---|---|---|
| Spain | 1,439 | 3,609 |
| France | 2,308 | 2,173 |
| Italy | 424 | 1,390 |
| Other countries | 465 | 678 |
| **Sub-Total** | **4,635** | **7,850** |
| Brazil | 1,554 | 1,435 |
| USA | 14 | 124 |
| Canada | 8 | 95 |
| Venezuela | 35 | |
| Other countries | | 53 |
| **Sub-Total** | **1,611** | **1,707** |
| **Total** | **6,247** | **9,557** |

Source: Direcção Regional Agricultura Trás-os-Montes

### Major pests and diseases

Chestnut trees are planted at 600-900 m in Portugal. Although most of Portugal has a mild Mediterranean climate, this part of the country is characterised by cold winters and hot, dry summers. The major chestnut cultivation diseases are ink disease and chestnut blight. The major pest problems are *Cydia splendana* Hubner and *Balaninus (Curculio) elephas* Gyll that can reach final larva instar in the fruit at harvest time. *B. elephas*one is not spread over the entire production region but is found only in some localities or in some varieties where it can cause a serious infestation. In the worst years, both pests can destroy about 25% of the production and cause 50% loss in the final period of harvest. No insecticides are registered for use during the production of chestnuts which places great reliance on a postharvest treatment to control any infested fruit.

## DISINFESTATION TREATMENTS

### Methyl bromide fumigation

For the domestic market the fruits, in general, are simply picked and sized. No MB fumigation is carried out for shipments within the European Community.

Chestnuts exported from Portugal are treated with MB prior to export. Some exporters use concrete fumigation chambers based on recommendations developed 20 years ago. More recently, exporters cover the consignments with plastic film as more chestnuts can be treated compared to the chambers.

In Trás-os-Montes, chestnuts are fumigated in October and November at 48-50 $gm^{-3}$ for 24 hours at ambient temperatures (0-16°C) to control *Cydia splendana* Hubner and *Balaninus (Curculio) elephas* Gyll. The exposure period is lengthy to compensate for the cooler temperatures that typically occur at that time of the year.

### Development of methyl bromide alternative technologies

When considering alternatives to replace MB fumigation of chestnuts exported from Portugal, a range of potential alternatives to MB were considered based on the research undertaken mainly in Japan. A summary of this research is provided in Table 2.

Table 2: Potential alternatives to methyl bromide tested mainly in Japan*.

| No. | Methyl bromide alternative | Technology summary and key results | Technical reason for not being feasible |
|---|---|---|---|
| 1 | Methyl iodide fumigation | Fumigation with 30-50g/m3 for 2-4 hours at 15ºC/or room temperature. Complete kill was observed in 40g/m3-4hours and 50gr/m3-3 hours | Equal efficacy as MB. Toxicity and phytotoxicity assessment is required because it is unregistered. |
| 2 | Sulfuryl fluoride fumigation | Fumigation with 30-40gr/m3 for 2-4 hours, 15-25ºC. Incomplete kill in spite of 40gr/m3 for 4hours. The effect to eggs is small. | Toxicity and phytotoxicity assessment is required because it is unregistered. |
| 3 | High pressure carbon dioxide | CO2 pressure treatment for 10-30min.at 2.5Mpa or 3.0Mpa. Complete kill in both pressure for 30min. Equal efficacy as MB. | Equipment of high-pressure resistant facilities costs a lot and a large amount of chestnuts cannot be treated. |
| 4 | Phosphine fumigation | Fumigation with 1.5 and 2g/m3, for 24-48 hours, at 15-25ºC.90-95% mortalities were obtained in 2gr/m3 at 25ºC. | Inferior efficacy compared to MB. Chemical injury occurs. |
| 5 | Aluminum phospide fumigation | Fumigation with 5-10gr/m3, for 2-28 hours at room temperature. Insecticidal effect is small. | Inferior efficacy to MB. Severe chemical injury occur. |
| 6 | Carbon dioxide under low temperature | CO2 fumigation: concentration 67-89, temp. 0 to -2.5ºC, for 4-16 days. All tested plots cannot obtain complete mortality. | Practical use is difficult because insecticidal effect is small. |
| 7 | Carbon dioxide | CO2 fumigation: 100% concentration of CO2, 1-8 days. Only 88,9% mortality was obtained for 8 days. | Insecticidal effect is small. And chemical injury occurs with fermentation. |
| 8 | Allyl isothiocyanate | Treatment: 1000, 3000 ppm, for 3-24 hours at room temperature.3000 ppm for 24 hours provide 96,8% mortality. | Inferior efficacy compared with MB. Chemical injury occur (deterioration of fruit pulp and mustard odour). |
| 9 | Dried heat | Temperature 40-90ºC.More than 70ºC provide 100% mortality. | Practical use is difficult because deterioration of quality occur. |
| 10 | Hot water | Treatment:40-60ºC of hot water, for 30-120 minute. Complete kill was obtained above 50ºC. | Practical use is difficult. Deterioration of quality occur (discoloration and strong odour). |
| 11 | Water immersion | Water immersion for 3-14 days.3days show 90%and 7 days show 90% and 50% survival rate respectively. Only 14 days show 100% mortality | Practical use is difficult. Deteriorations of quality occur. |
| 12 | Spray control | 400 litters of spray of 1,500 time solution of Pyrethroid to trees in an 10a area. No effect on eggs and larvae. | Practical use is difficult because insecticidal effect is small. |

*These experiments were made by several Prefectural and National Experiment Stations of the Ministry of Agriculture, Forest and Fisheries, from 1999 to 2003.

The most promising alternative was shown by Japan was fumigation with methyl iodide. However, further research would be required to determine the impact of methyl iodide on the quality of fresh chestnuts. In addition, residue work would need to be carried out in order to satisfy the relevant authorities that residues did not exceed permitted levels.

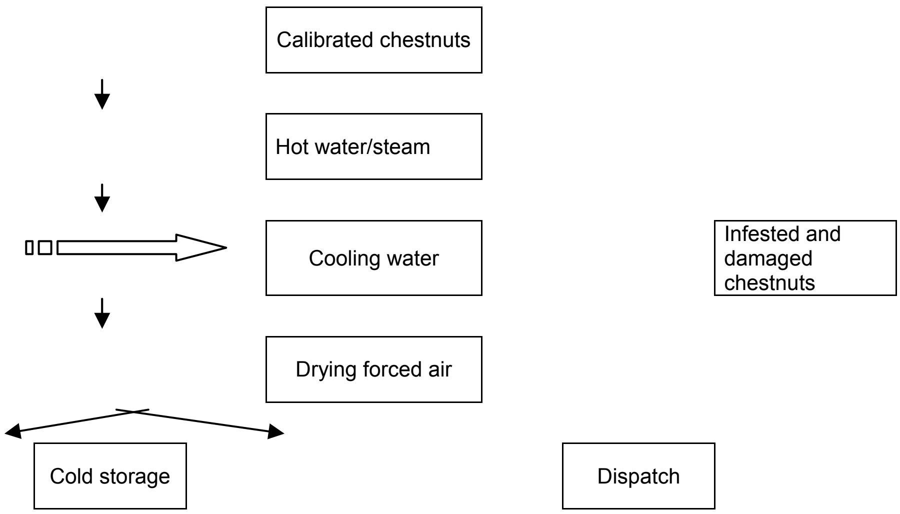
In order to avoid difficulties associated with the potential implementation of a chemical treatment such as methyl iodide, a physical treatment was selected based on heat. A combination of water and steam was considered to be the most promising, particularly the development of a treatment that modified previous research to avoid any deterioration in quality of the fresh chestnut.

**Hot water / steam treatment**

A hot water / steam treatment was developed and has been in use since 1992 by Sortegel, a company located near Bragança. The chestnuts pass continuously through water/steam at 48ºC-50ºC for 30-45 minutes. The chestnuts are then cooled in a tank of water in which the infested fruit floats to the surface and is automatically discarded. The chestnuts are dried with forced air for about 30 minutes. It is essential to aerate the chestnuts for 48 hours to prevent fermentation during shipment.

This equipment is expensive and the cost of the chestnuts is about 20% higher than those treated with MB. It is applicable only to chestnuts. This treatment is accepted by Canada and Brazil.

The overall scheme is as follows:

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## THE USE OF SULPHURYL FLUORIDE IN EUROPE FOR STRUCTURE AND COMMODITY DISINFESTATION

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### ABSTRACT

Following laboratory and field trials on the efficacy, physical properties and safety of sulphuryl fluoride (SF), the compound is now coming into commercial use under a manufacturer's stewardship programme for the treatment of cereal grain mills, food processing and storage facilities as the fumigant ProFume®, starting from July 2003 in Switzerland. Further tests are planned for Italy and the UK in the summer of 2004. The use of methyl bromide (MB) in Europe has fallen from about 18,000 tonnes in 1991 to a current estimate of 6000 tonnes and is scheduled to fall further in 2005 when only critical and quarantine-related uses will remain. Some 336 tonnes of MB have been requested in Europe for treatment of flour mills and cereal processing facilities as a critical use exemption area. The availability of SF for this use will decrease this need substantially. Much of the other post harvest uses of MB currently fall in the quarantine and pre-shipment category but there is also potential here for replacement of at least some of these uses with SF.

**Key words:** Disinfestation, mills, food processing facilities, food commodities, methyl bromide alternative, physical properties, efficacy, registration, sulfuryl fluoride, Profume®

### INTRODUCTION

Fumigation with methyl bromide (MB) has long been used as a front line defence in the food industry for the disinfestation of stored product insects from structures, equipment and food commodities. Sulphuryl fluoride (SF) offers one of the very few options as a 'like for like' replacement now that methyl bromide is being phased out under the Montreal Protocol as a potential depletor of stratospheric ozone. Following a still continuing research programme initiated by Dow AgroSciences in cooperation with academic, government and industry partners, registration applications have been submitted in the USA, Switzerland, Italy, the UK, Canada, France and Germany.

In June 2003, government authorities in Switzerland granted the first approval of SF (as the product ProFume® gas fumigant) for use in emptied mills, storage facilities and silos. This was followed in January 2004 by the Environmental Protection Agency granting Federal registration in the USA for use in grain milling and storage as well as dried fruit and tree nut processing and storage; approval in Italy in April 2004 for disinfestation of flour, semolina and pasta mills; and in the UK in July 2004 for treatment of emptied cereal grain mills and storage facilities. The trial results to date and prospects for future replacement of MB for post harvest uses throughout Europe are discussed.

### SUMMARY OF TRIALS WORK WITH SULFURYL FLUORIDE IN EUROPE

#### Tests on insect pests

Data are now available on over 50 species of insects infesting food or timber products (Table 1), with particular emphasis on pests of flour mills. Of these the most tolerant stage is the egg. The highest tolerance so far encountered is in certain strains of the rust-red flour beetle *Tribolium castaneum* (Herbst). The concentration time product (Ctp) required for control depends on the temperature and exposure period applied. For example at 30°C control of *T. castaneum* can be achieved in a 24-h exposure by a Ctp that is 4-fold lower than at 20°C at which the Ctp required exceeds 4000 g.h/m$^3$. Increasing the exposure time from 20 to 120 hours at 30°C reduces the Ctp needed for control of eggs of *Rhyzopertha dominica* by 67.5% . The advantage of longer exposure times at a reduced dose is because eggs continue to develop when exposed to SF and the newly-formed larvae die as they approach hatch (Bell *et al.* 2004).

Table 1. Structure and food pests for which some data exist on their susceptibility to sulphuryl fluoride

| Structure/commodity | Insect and mite species |
|---|---|
| Logs, timber, buildings | *Hylotrupes bajulus, Euvrilletta peltata, Hemicoelus gibbicollis, Anoplophora glabripennis*, Lyctus planicolis, Lyctus brunneus, Coptotermes formosanus*, Kalotermes spp.*, Incisitermes spp.*, Reticulitermes spp.*, Cryptotermes spp.*, Neotermes spp.*, Zooteropsis spp.** |
| Museum artefacts, archives, fabrics | *Attagenus unicolor, Anthrenus flavipes, Trogoderma inclusum, Liposcelis bostrychophila, Tineola bisselliella* |
| **Cereal grains** | *Sitophilus granarius, Sitphilus oryzae, Rhyzopertha dominica, Cryptolestes ferrugineus, Ahasverus advena, Oryzaephilus surinamensis, Sitotroga cerealella, Trogoderma granarium, Cynaeus angustus*, Tenebroides mauritanicus** |
| Flour and cereal products | *Tribolium castaneum, Tribolium confusum, Cryptolestes turcicus, Ephestia kuehniella, Gnatocerus cornutus, Ptinus tectus, Stegobium paniceum, Tenebrio molitor, Trogoderma variabile, Acarus siro* |
| Dried fruit, nuts, beverages and spices | *Plodia interpunctella, Ephestia cautella, Ephestia elutella, Lasioderma serricorne, Carpophilus hemipterus* |
| Fresh fruit, vegetables, chestnuts | *Ceratitis capitata, Bactrocera dorsalis, Bactrocera cucurbitae, Prodenia eridania, Paramyelosis transitella*, Cydia splendana*, Curculio elephas** |
| Dried animal products, food residues | *Dermestes maculatus, Blatella germanica*, Periplaneta americana, Supella longipalpa, Musca domestica** |

*Data for post-embryonic stages only

### Tests in flour and other mills

Some 20 trials have been carried out in Europe, featuring mills, chambers and stacks in Germany, Switzerland, Italy, the UK and France (Drinkall, *et al*., 2003; Ducom, *et al*., 2003; Reichmuth, *et al*., 2003; Bell *et al*., 2004). The emphasis in all trials has been to reduce half loss times in the structure though improved sealing of the structures. Improvements in temporary and permanent sealing is desirable not only for the use of SF but for all other fumigants. In some instances where ambient temperatures have been below 25$^{o}$C, heating has been applied to improve efficacy. The objective has been to fit the SF fumigation into the existing time frame used for MB treatments and hence the time under gas has been in the region of 24 hours. In most cases a Ctp of 1400-1500 g.hm$^{-3}$ was aimed for and achieved in the trial fumigation. Insect bioassays were included in many fumigations and showed either total kill of all stages or very high levels of control. The trials also examined venting procedures and environmental monitoring of gas concentrations in the area surrounding the buildings under fumigation.

### Tests on products and materials – some advantages of SF over MB

One of the key advantages of SF over MB is the very low boiling point of -55.2$^{o}$C at atmospheric pressure. This gives rise to a vapour pressure of 13,442 mm Hg at 25$^{\circ}$C compared to only 1,610 mm Hg for MB which boils at 4.2$^{\circ}$C. This more than offsets the slightly greater vapour density of 3.52 and the gas disperses readily in air. SF has been found to penetrate flour about 10 times more rapidly than methyl bromide. SF concentrations at a depth of 30 cm reach 60% of the surface level within 3 hours at 18 – 28$^{\circ}$C (Bell *et al.*, 2004). The level of SF sorbed by flour is also less than one tenth that of MB. In spite of its increased powers of penetration through flour and wood, SF has shown a much lower rate of permeation through polythene sheeting and polyurethane paint than MB which is an advantage when sealing enclosures. The permeation through LDPE sheeting at 0.21 gh$^{-1}$m$^{-2}$ (MB = 50 gh$^{-1}$m$^{-2}$) was comparable to MB permeation through virtually impermeable (VIF) sheeting.

In the absence of moisture, glass or copper samples exposed to SF remain untarnished and computers remained operational after a variety of test exposures, including one in which the temperature reached 70$^{\circ}$C, having withstood an accrued CTP of over 40,000 g.hm$^{-3}$, a dosage equivalent to over 25 practical mill fumigations (Bell *et al.* 2004).

## PROGRESS TOWARDS REGISTRATION AND COMMERCIAL ADOPTION OF SULFURYL FLUORIDE IN EUROPE

The first country to approve SF (as ProFume®) for commercial use for use in the food industry was Switzerland on 30th June 2003. Subsequently, the first commercial fumigation of a flour mill was carried out near Luzern between the 17th and 20th July, 2003 (Schreyer *et al.*, 2003). The mill, of volume 4,318 $m^3$, was sealed to a half-loss time of 27 hours and treated successfully. A progressive phase-out of MB for this use is scheduled over a two-year period as commercial fumigators working under the stewardship training programme developed by Dow AgroSciences build their expertise in applying the new fumigant and logging the characteristics of each fumigation site. Following the registrations in Italy and the UK in April and July 2004, commercial fumigations were initiated in 2004 in cereal grain mills. Registration submissions have also been made in Germany and France with further registration submissions planned to extend the product label to include food commodities e.g. dried fruit, tree nuts and cereal grains.

## THE POTENTIAL FOR METHYL BROMIDE REPLACEMENT BY SULFURYL FLUORIDE IN EUROPE FOR STRUCTURES AND COMMODITIES

### Data on methyl bromide usage in Europe

In Europe countries have been following an accelerated MB phase-out schedule formulated by the EU in 1997 with the 25% use reduction coming in 1998 instead of 1999 as in the Montreal Protocol, a 60% instead of 50% use reduction operating from 2001 and a 75% instead of 70% reduction operating from 2003, before phase-out in 2005. From a baseline level in 1991 of over 18,000 tonnes, MB use in Europe has now fallen to an estimated maximum usage level of 6,000 tonnes (Table 2) of which about 30% is for Montreal Protocol exempted quarantine and pre-shipment uses. Much of the remainder is required for various uses in horticulture for which alternatives have not yet been commercially established and hence the further use reduction achieved at phase-out in 2005 is likely to be modest until alternatives become available for the critical uses approved under the Montreal Protocol exemption procedure.

Table 2. Data (tonnes) on methyl bromide use worldwide (including estimated quarantine and pre-shipment uses) and in Europe (Data extracted from UNEP 1999, 2003).

| Year | Total world wide | Total for QPS uses | Total use in Europe |
|---|---|---|---|
| 1991 | 72,689 | - | 18,020 |
| 1995 | 66,339 | - | 16,350 |
| 1997 | 62,750 | - | 17,000 |
| 1998 | 71,000 | 8,250 | 12,000 |
| 1999 | 61,500 | 12,200 | 12,700 |
| 2000 | 57,000 | 11,600 | 11,000 |
| 2001 | 50,000 | 10,000 | 8,500 |
| 2003 | 40,000* | 10,000 | 6,000* |

*Based on the transition from 40% to 25% of non exempt 1991 baseline levels in Europe, and from 50% to 30% for non Article 5(1) counties elsewhere

Many applications have been made to UNEP by European Member States for critical use exemptions to continue specified uses of MB for pre- and post-harvest treatments in the years 2005 and 2006. For the post harvest sector, some 35 critical use nominations (CUNs) have requested 380 tonnes out of the world total of 1414 tonnes for this sector. This total requested for the post harvest sector represents about 9% of the total request for critical uses of MB worldwide. Most of the European request in this sector (336 tonnes) is for use in flour milling and cereal processing, as is the case for post harvest requests worldwide (Table 3). It is this amount of MB that there is potential for a complete replacement with SF.

**The economics of switching from to methyl bromide to sulfuryl fluoride**

Increased standards required by registration authorities, including accuracy of dosage, operator and bystander safety and environmental risk, may result in increased costs of fumigation. For 24-hour structural treatments, fumigations with SF will require the application of considerably more gas than when using MB. Increasing exposure time or increasing the temperature can however reduce the amount of gas needed. Lost production on a daily basis and increased energy costs will need to be balanced against the possible savings obtained by reducing the amount of fumigant required. Costs of MB continue to rise from $5 per kg as the phase-out proceeds and the price differential between the two gases may decrease as a result. Costs of SF are still under review at the present time as the product is launched commercially in several different countries.

Table 3. Summary of critical use applications to the Montreal Protocol by sector for 2005

| Crop or use | Tonnes MB requested |
|---|---|
| Tomatoes | 4012 |
| Strawberry fruit | 2948 |
| Peppers and Egg plant | 2447 |
| Cucurbits | 1422 |
| Mills and Food Processors | 910 |
| Cut flowers | 837 |
| Miscellaneous | 2860 |
| *Total* | *15436* |

## CONCLUSIONS

SF offers the closest prospect for a like-for-like replacement of MB in the post-harvest sector for many uses. It offers a viable prospect for whole site disinfestation, an area of MB use that has been difficult to replace. The use of supplementary heating or longer exposure times in cooler climates should provide options for improving effectiveness while keeping treatment costs down. Improvement in dosage accuracy and adoption of stewardship programmes should increase fumigation efficiency as the characteristics of each site are noted. Registrations in several leading European countries are appearing for cereal grain mills and food processing facilities and registration applications for various commodity groups are in the pipeline.

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# UPDATE ON METHYL BROMIDE AND OZONE DEPLETION

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## ABSTRACT

According to the 2003 World Meteorological Organisation (WMO) report on the scientific assessment of ozone depletion methyl bromide (MB), the budget for the natural and anthropological sources and sinks cannot be balanced. On the basis of the WMO assessment, a steady state ozone depletion potential (ODP) of 0.38 has been recommended for MB. A phase-out schedule for MB has been agreed by the governments to the Montreal Protocol. An update is provided using current observations of MB concentrations recorded at the Mace Head (Ireland) and Cape Grim (Tasmania) atmospheric baseline monitoring stations. An analysis of the seasonal variations at these two sites reveals discrepancies with the current understanding of MB sources and sinks. Recent seasonal measurements make it likely that the atmospheric lifetime of MB is 1.28 -1.42 years which is significantly longer than 0.6 years currently estimated. Hence, the steady state ODP is estimated as 0.7 – 0.8 which is significantly greater than 0.6 adopted by the Montreal Protocol and 0.38 reported by the WMO.

**Keywords:** methyl bromide, sources, sinks, ozone depletion potential, ODP

## INTRODUCTION

Methyl bromide (MB) is the dominant bromine-carrier to the stratosphere and has both natural and man-made sources (WMO1991). The main natural sources are thought to be sea-weeds in coastal waters and phytoplankton in the open ocean (Gschwend *et al.* 1985; Tokarczyk & Moore 1994). However, the marked inter-hemispheric gradient between the northern and southern hemispheres is only consistent with there being substantial land-based sources, whether natural or man-made (Penkett *et al.* 1985). MB has been recognised under the Montreal Protocol and its amendments as an important ozone-depleting substance. However, because it is produced by the biosphere and is emitted into the atmosphere by natural processes, the case for the control of its man-made sources has been far more complex than for any other ozone-depleting substance (WMO 1994).

The World Meteorological Organisation report identified the following MB sources: oceans, 63 Gg $yr^{-1}$; fumigation, 40.8 Gg $yr^{-1}$; motor vehicles, 5 Gg $yr^{-1}$; biomass burning, 20 Gg $yr^{-1}$; wetlands, 4.6 Gg $yr^{-1}$; salt marshes, 14 Gg $yr^{-1}$; vegetation, 11.7 Gg $yr^{-1}$ (WMO 2003). The total sources was given as 159 Gg $yr^{-1}$, with a range from 77 to 293 Gg $yr^{-1}$. The following sinks for MB were identified: oceans, -77 Gg $yr^{-1}$, OH oxidation and photolysis, -80 Gg $yr^{-1}$ and soil uptake, -47 Gg $yr^{-1}$. The total sinks was given as -204 Gg $yr^{-1}$ with a range from -129 to -387 Gg $yr^{-1}$. The calculated budget remained out of balance by about -45 Gg $yr^{-1}$, with sinks outweighing sources and the best estimate global atmospheric lifetime standing at $0.7 \pm 0.4$ years (WMO 2003). The steady state ozone depletion potential was accordingly assessed at 0.38. This value is considerable lower than the ODP recorded by the Montreal Protocol of 0.6 (UNEP 2003).

## UPDATING OUR UNDERSTANDING OF THE LIFE CYCLE OF METHYL BROMIDE

Trends in the atmospheric concentrations of MB during the 20$^{th}$ century have been reconstituted by Butler *et al*. (1999) and Sturges *et al*. (2001) from records of its concentration in the air trapped in Antarctic firn (unconsolidated snow). Firn records indicate the mole fractions of MB that existed before the industrial production began. They therefore characterise the pre-industrial life cycle of MB. Furthermore, the increase in mole fraction during the last century can be used to quantify the contribution to the global budget of MB from human activities. The results suggested that southern hemisphere MB mole fractions have increased by about 2 to 2.5 ppt over the period from 1950 to 1995 and that 1950 levels were about 6 ppt. An increase in mole fraction of 0.7 ppt was also inferred for the early part of the $20^{th}$ century.

Reeves (2003) applied a global two-dimensional (altitude-latitude) chemistry-transport model to interpret the firn data using literature information concerning the sources and sinks of MB. The conclusion was reached that if all the natural sources - oceans, biomass burning and salt-marshes - were at their upper limits then the atmospheric budget in 1950 could be balanced. If an atmospheric lifetime of 1 year was taken instead of the literature value of 0.6 years, then the increase from 1950 through to the present day could be accounted for by the man-made use of MB. The increasing levels during the early part of the $20^{th}$ century required an increasing but unknown source term or a decreasing sink term. If the literature sources and atmospheric lifetime of MB are indeed correct, then additional increasing sources are required throughout the $20^{th}$ century, in both hemispheres. The nature of these sources could not be ascertained in the Reeves (2003) study.

More recently, Saltzman *et al.* (2004) presented the first measurements of MB from an Antarctic ice core. The mean MB mole fraction reported was $5.8 \pm 0.3$ ppt with an increasing time trend of 0.005 ppt $yr^{-1}$ over the period from 1717 to 1942. The ice core data do not sufficiently constrain the MB budget to determine how much of the current inbalance of sinks over sources was present in the pre-industrial budget. It is important to determine whether the unknown sources required to balance the current MB budget are man-made or natural. It is likely that most of the unknown sources required in the current southern hemisphere are not man-made. Furthermore, a large unknown source is required in the pre-industrial southern hemisphere. A major unknown turned out to be the magnitude and distribution of pre-industrial biomass burning emissions of MB. A major limitation appeared to be the lack of ice core data for the northern hemisphere.

Yvon-Lewis *et al.* (2004) have measured the air and water concentrations of MB in the Southern Ocean (latitude $45^o$ – $67^o$ S, longitude $144^o$ – $139^o$ E) from late October through to mid-December 2001. MB was undersaturated suggesting that there were no significant ocean sources in this region and at this season.

Simmonds *et al.* (2004) have reported *in situ* measurements of MB using GC-MS at the AGAGE atmospheric baseline stations at Mace Head (Ireland) and Cape Grim (Tasmania) for the period from 1998 – 2001. At Mace Head, MB showed a well-defined seasonal cycle and a downward trend of -3.0% $yr^{-1}$. The mean northern hemisphere baseline mole fraction observed was $10.37 \pm 0.05$ ppt. At Cape Grim, virtually no seasonal cycle was evident in the observations but a well-defined downwards trend of 2.5 % $yr^{-1}$ was observed. The mean southern hemisphere baseline mole fraction observed was $7.94 \pm 0.03$ ppt. MB is decreasing in both locations and so this implies that a change has occurred which is affecting a common and major source or sink. If the downwards trend is not solely attributable to a reduction in emissions from fumigation use, then a more complex mix of changes must provide an explanation.

Figure 1 illustrates the observed time series of MB observed by Simmonds *et al.* (2004) at Mace Head for 2000 and 2001. The presence of a clear seasonal cycle is demonstrated in the northern hemisphere baseline mole fractions, shown as blue crosses. Also evident are elevated mole fractions in regionally-polluted air masses advected to the Atlantic Ocean coastline of Ireland from time-to-time, shown as red crosses.

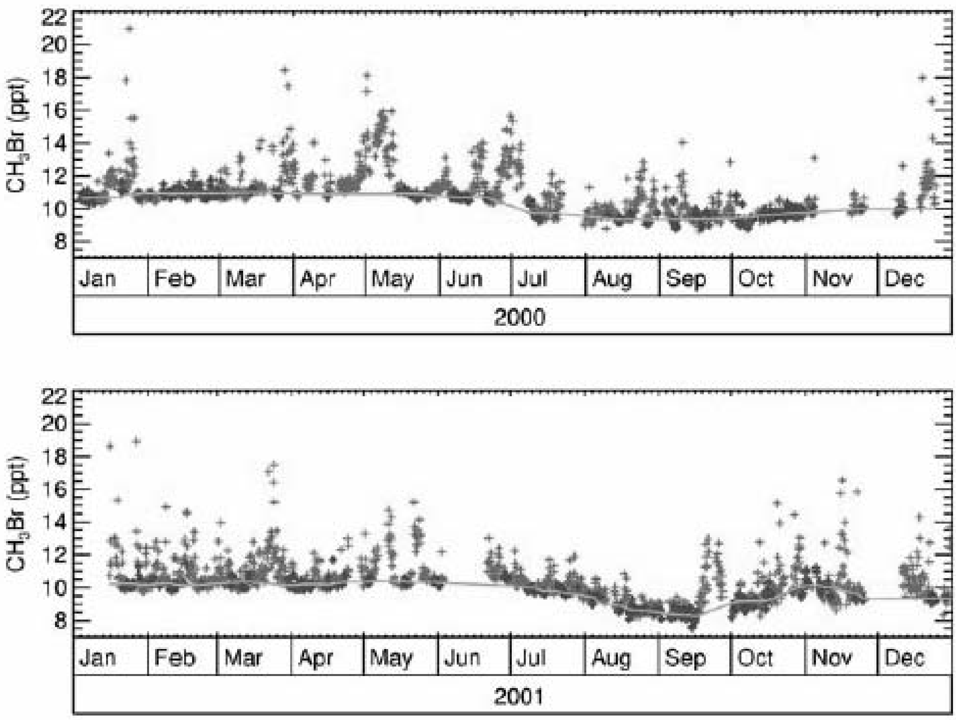


Figure 1: Time series of MB mole fractions (1 ppt = $10^{-12}$) at Mace Head (Ireland) during 2000 and 2001 taken from Simmonds *et al.* (2004). Red symbols indicate regionally-polluted air masses, blue symbols represent baseline data and the light blue line is a smooth curve through the baseline data.

## INTERPRETATION OF THE OBSERVED SEASONAL CYCLES IN METHYL BROMIDE AT MACE HEAD AND CAPE GRIM

Observations of the mole fractions of MB at the atmospheric baseline stations at Mace Head and Cape Grim show distinctly different seasonal cycles. A pronounced seasonal cycle is observed at Mace Head, in contrast to Cape Grim where little seasonality is seen. A global Lagrangian 3-D chemistry transport model has been used to describe the seasonal cycles at Mace Head and Cape Grim for a range of different combinations of natural and man-made sources and sinks.

A 'best' fit to the observed seasonal cycles was obtained with global patterns of sources and sinks which departed radically from those in the literature. The modelling studies suggested an atmospheric lifetime of MB in the range between 1.28 and 1.42 years. This study would therefore suggest an atmospheric lifetime for MB that is significantly longer and a fraction of observed MB that is of man-made origins that is significantly higher than current literature estimates.

These discrepancies may warrant a reconsideration of the importance of MB as a carrier of bromine to the stratosphere and its ozone depletion potential ODP. On this basis, the steady state ODP of MB should be in the range 0.7 – 0.8, compared with the WMO (2003) value of 0.38 and that adopted in the Montreal Protocol of 0.6 (UNEP 2003).

## ACKNOWLEDGEMENTS

This analysis of the seasonal cycles in MB was supported by the Global Atmosphere Division of the UK Department for Environment, Food and Rural Affairs under contract no. EPG 1/1/142. The operation of the AGAGE station at Mace Head was supported under contract no. EPG 1/1/130.

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# INTERNATIONAL MPS CERTIFICATION SYSTEM FOR CUT-FLOWER PRODUCTION

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## ABSTRACT

Milieu Programma Sierteelt (MPS) is an international environmental certification accredited by the Council for Accreditation pursuant to in EN 45011 and ISO/IEC Guide 65. The mission of MPS is to stimulate environmentally-aware cultivation and to reduce the environmental burden caused by pollution. More than 5,200 farmers from 31 countries worldwide have implemented the MPS programme, producing cut-flowers, ornamental plants, bulbs, and nursery stock on a total area of about 20,000 ha. Growers who participate in the MPS programme must keep records and reduce where possible their use of pesticides, fertilisers, energy, water, waste and other factors. The MPS standards prohibit the use of certain highly toxic chemicals including methyl bromide. Each producer's environmental performance is judged according to regional standards, based on regional bench-marking. When the flowers are sold at wholesale level in auction houses in Europe, a number of purchasing companies buy MPS certified flowers in preference to normal flowers. Some supermarket chains purchase only MPS certified flowers. Information is provided on the process of expansion of the MPS programme to new countries.

## INTRODUCTION

Milieu Programma Sierteelt (MPS) is an international environmental certification and grading system founded in 1995 that operates in the cut flower sector in many countries. Although there are other flower certification programmes MPS is the market leader. MPS covers cut-flowers, ornamental plants, bulbs, and nursery stock.

The MPS programme was set up about ten years ago as a result of consumer concerns about agriculture such as BSE (mad cow disease), dioxin contamination of poultry, excessive use of pesticides and similar problems that acted to reduce consumer confidence in farming methods. MPS tries to prevent problems such as these arising and thereby reduce the costs of ameliorating such problems. MPS believes that production must respect nature, flora, fauna and humans, and therefore it is important not to pollute the soil, water and air. The mission of MPS is to stimulate environmentally-aware cultivation and to reduce the environmental burden caused by pollution.

## PARTICIPATION IN MPS PROGRAMME

More than 5,200 farmers implement the MPS programme through production that covers on an area of about 20,000 ha. Farms from 31 countries participate in the programme including those from *Europe:* The Netherlands, Belgium, Denmark, France, Spain, Portugal, Germany, England, Poland, Ireland; *Africa:* Kenya, Tanzania, Uganda, Ethiopia, Zambia, Zimbabwe, South Africa; *Latin America:* Costa Rica, Honduras, El Salvador, Guatemala*; South America:* Ecuador, Colombia, Brazil*; North America*: United States and Canada; *Asia:* India, Sri Lanka, Malaysia; and the *Middle East:* Israel, Egypt.

## MPS STANDARDS

MPS is a monitoring and auditing system. Growers who participate in the MPS programme must keep records and reduce where possible their use of pesticides, fertilisers, energy, water, waste and other factors. Each producer's environmental performance is judged according to regional standards, based on regional bench-marking.

Producers receive scores according to their use of chemicals, fertilizers and other production inputs. An MPS grower records usage every four weeks for: 1/ Crop protection agents; 2/ Fertilisers; 3/ Energy; 4/ Waste; and 5/ Water usage. The MPS standards prohibit the use of certain highly toxic chemicals including methyl bromide (MB) which cannot be used in the production of MPS grade flowers.

The scores are used to determine an environmental qualification (A, B or C) for the products of each producer. MPS does not only concern itself with the environment, but safety, health and conditions of employment also play a role. Those MPS participants who meet all of the social requirements may use the “socially qualified” label on their product label. MPS has comprehensive and reliable audits in order to apply the environmental qualification.

MPS at international level is headed by a Board of growers. An international committee reviews the technical aspects. An international accreditation association is responsible for auditing and accreditation.

MPS meets the accreditation criteria for certification institutions as recorded in EN 45011 and ISO/IEC Guide 65. In June 1999 MPS was accredited by the Council for Accreditation as MPS is considered by the Council to carry out its activities ‘…expertly, impartially, reliably and with integrity’. For all practical purposes, it means that the qualifications MPS A, B and C are officially recognised quality marks, thus forming a guarantee for the market**.**

## REGISTRATION OF NEW COUNTRY

The process of establishing MPS in a new country can be as follows:

┤A:

- A pilot group of growers is willing to trial the programme and develop local bench-marks for use of pesticides, fertilisers, water and other factors;
- MPS representatives visit to explain the system and show how it is done;
- It normally takes approximately one year to train and set up the necessary changes for the pilot;
- After about 1 year of the pilot, MPS representatives evaluate the progress with growers and a local research station, and set the local standards and scoring system;
- Each grower who participated in the pilot group must decide if they want to continue or not with MPS; and
- Growers pay to participate in MPS, or get funds/support from external sources

┤B:

- At individual base
- The grower sends a list of chemicals and fertilisers used to MPS
- MPS adds this information to the database and looks for a comparable country
- See the points mentioned for pilot group
- It is more expensive as a pilot, but it is possible

## INTERNATIONAL SALES OF CUT-FLOWERS

When the flowers are sold at wholesale level in auction houses in Europe, a number of purchasing companies buy MPS certified flowers in preference to normal flowers. Some supermarket chains purchase only MPS certified flowers. An increasing number of growers have chosen to become member of the MPS certification programme because the prospects are improved for obtaining a sale at a better price in the main international auctions.

Traders who specifically choose to purchase MPS products and meet the MPS requirements may become recognised as “MPS traders”. This label allows them to take advantage of a growing demand from the market. MPS traders are entitled to use the MPS label in their distribution.

Florists who specifically choose to purchase a certain percentage of MPS products and meet the MPS requirements may become recognised as “MPS florists”. This allows these florists to take advantage of a growing environmental awareness and to offer customers a ‘greener’ alternative. MPS florists may use the MPS label in presenting their participation.

MPS provides an international system and framework and organises audits and inspections. Traders and florists are able to use MPS as a tracking system for cut-flowers which helps with making improvements to operations.

## REFERENCES

For further information please go to the MPS website www.my-mps.com

**REDUCING THE USE OF METHYL BROMIDE VIA EUREPGAP - THE PRIVATE SECTOR HOLISTIC APPROACH**

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## ABSTRACT

Retailers together with agricultural producers developed a series of good agricultural practice standards, which then became parts of individual trade agreements between food buyers and sellers. This holistic industry platform is called EurepGAP, The Global Partnership for Safe and Sustainable Agriculture. The paper explains, with the example of the EurepGAP Standards for Fruit and Vegetables and for Flower and Ornamentals, how the private sector takes on responsibility in assuring principle attributes of food products including food safety, environmental, social and animal welfare issues. A system of interfaces is proposed to demonstrate the opportunities to increase private-public strategic alliances in order to address a common target: of reducing the use of methyl bromide.

**Keywords:** EUREPGAP, methyl bromide, private-public interface, fruit and vegetables, alternatives

## INTRODUCTION

The private sector continues to take on responsibility in assuring principle attributes of food products. While for legislators and food business assuring food safety has been the number one priority, other issues including environmental, social and animal welfare now climb up the ladder of public concern. Businesses respond to those trends, especially where they are exposed directly to the final consumer. One of the most powerful groups is the food retailers represented mainly by the supermarket chains, jointly followed by international restaurant and food service chains.

On the platform of EurepGAP, the Global Partnership for Safe and Sustainable Agriculture, are those retailers together with agricultural producers that have developed a series of good agricultural practice standards. These standards have now become parts of individual trade agreements between food buyers and sellers.

## BENEFITS OF EUREPGAP STANDARDS

Some benefits of the worldwide EurepGAP standards are:

- Producers have harmonised rules with less double controls;
- Producers receive and maintain access to global food chains by complying with EurepPGAP;
- Producers can demonstrate their achievement in a transparent way to customers and the public;
- Producers can actively be involved in developing the standard, merging practicality with market requirements;
- Retailers can show consumers and the public sector their involvement and achievement in meeting their demands of the standards in regard to food safety, environmental compliance, worker health and safety, and animal welfare;
- All partners of the food chain can reduce costs and increase efficiency by applying a single standard rather than developing and implementing individual solutions;
- The entire sector has free access to the EurepGAP standards and can progress regardless of the direct link to supporting members of EurepGAP; and
- Via a transparent benchmarking process, other standards can receive be recognised as equivalent to EurepGAP, thereby avoiding duplication.

## ACHIEVEMENTS OF EUREPGAP

Overall achievements of EurepGAP standards implementation include the development of standards to date for Fruit and Vegetables; Flowers and Ornamentals; Integrated Farm Assurance – Livestock and Combinable Crops; Coffee; and Integrated Aquaculture Assurance.

Certification activities are taking place in more than 45 counties world-wide. Some retailers have switched their entire fruit and vegetable sales towards EurepGAP sources, others will follow by the end of 2004.

## METHYL BROMIDE AND EUREPGAP

Reducing the use of agrochemicals such a methyl bromide belongs to the EurepGAP Terms of Reference. Chemical soil fumigation is addressed in the Fruit and Vegetables Standard Version 2 (January 2004) and the EurepGAP Standard for Flowers and Ornamental Version 1 (Jan. 2004). Extracts from this standard are shown for three sections, particularly those related to the use of methyl bromide and its alternatives.

| **5. SOIL AND SUBSTRATE MANAGEMENT** | | | |
|---|---|---|---|
| **5.4 Soil Fumigation** | | | |
| 5.4.1 | Is there a written justification for the use of soil fumigants? | There is written evidence and justification for the use of soil fumigants including location, date, active ingredient, doses, method of application and operator. | Minor |
| 5.4.2 | Are alternatives to chemical fumigation explored before resorting to the use of chemical fumigants? | The farmer is able to demonstrate assessment of alternatives to chemical soil fumigation through technical knowledge, written evidence or accepted local practice. | Recom. |
| **5.5 Substrates** | | | |
| 5.5.1 | Does the farmer participate in substrate recycling programmes for substrates where available? | The farmer keeps records with quantities recycled and dates. Invoices/loading dockets are acceptable. If there is no participation in a recycling program available, it should be justified. | Recom. |
| 5.5.2 | If chemicals are used to sterilise substrates for reuse, has the location of sterilisation been recorded? | When the substrates are sterilised on the farm, the name or reference of the field, orchard or greenhouse are recorded, if sterilised off farm then the name and location of the company which sterilises the substrate. | Major |
| 5.5.3 | If chemicals are used to sterilise substrates for reuse, has the date of sterilisation, type of chemical, method of sterilisation and name of the operator been recorded? | The following are all correctly recorded: the dates of sterilisation (day/month/year); the name and active ingredient; the machinery (e.g. 1000 l-tank etc); the method (e.g. drenching, fogging); and the operator's name (the person who actually applied the chemicals and did the sterilisation). | Minor |
| 5.5.4 | When substrates are reused, has steaming been used for sterilisation? | When substrates are reused, documentary evidence shows that steaming is the option used. | Recom. |
| 5.5.5 | Are substrates traceable to the source and do not come from designated conservation areas? | There are records that prove the origin of the substrates being used. These records demonstrate that the substrates do not come from designated conservation areas. | Recom. |

| 8. CROP PROTECTION | | | |
|---|---|---|---|
| **8.2 Choice of Chemicals** | | | |
| 8.2.1 | Is the crop protection product applied appropriate for the target as recommended on the product label? | All the crop protection products applied to the crop are suitable and can be justified (according to label recommendations or official registration body publication) for the pest, disease, weed or target of the crop protection product intervention. No N/A. | Major |
| 8.2.2 | Do farmers only use crop protection products that are registered in the country of use for the target crop where such official registration scheme exists? | All the crop protection products applied are officially registered or permitted by the appropriate governmental organisation in the country of application. Where no official registration scheme exists, refer to the EUREPGAP guideline in Annex 2 of this document and FAO International Code of Conduct on the Distribution and Use of Pesticides. No N/A. | Major |
| 8.2.3 | Is a current list kept of Crop Protection Products that are used and approved for use on crops being grown? | An up to date documented annual list is available of the commercial brand names of crop protection products (including their active ingredient composition, or beneficial organisms) that are used on crops being, or which have been, grown on the farm under EUREPGAP within the last 12 months. No N/A | Minor |
| 8.2.4 | Does this list take account of any changes in local and national crop protection product legislation? | The up to date documented list of all commercial brands of crop protection products that are used and officially registered for use on crops being currently grown on farm or which have been grown under EUREPGAP within the last 12 months has been updated according to all the applicable latest changes in crop protection product legislation re crop approvals, harvest intervals, etc. No N/A. | Minor |
| 8.2.5 | Are chemicals, banned in the European Union, not used on crops destined for sale in the European Union? | The documented crop protection product application records confirm that no crop protection product has been used within the last 12 months on the crops grown under EUREPGAP destined for sale within the E.U., having been prohibited by the E.U. (i.e. EC Prohibition Directive List - 79/117/EC and amendments). | Major |

| 5. SOIL AND SUBSTRATE MANAGEMENT | | | |
|---|---|---|---|
| **5.4 Soil Fumigation** | | | |
| 5.4.1 | Is there a written justification for the use of soil fumigants? | Methyl Bromide is not permitted after 31st December 2004. There is written evidence justifying the use of soil fumigants including location, date, active ingredient, doses, method of application and operator. | Req |
| 5.4.2 | Have alternatives to chemical fumigation been explored before resorting to use of chemical fumigants? | The grower should be able to demonstrate assessment of alternatives to soil fumigation through technical knowledge, written evidence or accepted local practice. | Enc |
| **5.5 Substrates** | | | |
| 5.5.1 | If substrates are used, are records available to demonstrate the suitability of these substrates? | There are records available that demonstrate the substrate's suitability for the specific crops grown e.g. technical specification of the substrate supplier, analysis results. | Req |
| 5.5.2 | Does the grower participate in substrate recycling programmes for substrates? | The grower must keep records with quantities recycled and dates. Invoices/loading dockets are acceptable. If there is no participation in a recycling program available, it must be justified. | Enc |
| 5.5.3 | If chemicals are used to sterilise substrates for reuse, has the location of sterilisation been recorded? | When the substrates are sterilised on the farm, the name or reference of the field must be recorded, if not then the name and location of the company which sterilises the substrate. | Req |
| 5.5.4 | If chemicals are used to sterilise substrates for reuse, has the date of sterilisation been recorded? | The dates of sterilisation must be recorded as day/month/year. | Req |
| 5.5.5 | If chemicals are used to sterilise substrates for reuse, has the type of chemical used been recorded? | The trade name and active ingredient must be recorded. | Req |
| 5.5.6 | If chemicals are used to sterilise substrates for reuse, has the method of sterilisation been recorded? | Type of machinery (e.g. 1000 l-tank etc) and method like drenching or fogging must be recorded. | Req |
| 5.5.7 | If chemicals are used to sterilise substrates for reuse, has the name of the operator been recorded? | The name of the person applying the chemical i.e. operator is the person who really applied the chemicals and did the sterilisation, is documented. | Req |
| 5.5.8 | When substrates are reused, has steaming been used as the preferred option for sterilisation? | When substrates are reused, steaming should be the preferred option. | Enc |
| 5.5.9 | Are substrates traceable to the source and do they not come from designated conservation areas? | There are records that prove the origin of the substrates being used. These records demonstrate that these substrates do not come from designated conservation areas. | Req |

| 8. CROP PROTECTION | | | |
|---|---|---|---|
| **8.2 Choice of crop protection products** | | | |
| 8.2.3 | Do growers only use chemicals that are registered in the country of use for the target crop where such official registration scheme exist, or, in its absence, comply with the specific legislation of the country of destination? | All the crop protection products applied are officially registered or permitted by the appropriate governmental organisation in the country of application. Where no official registration scheme exists, refer to the EUREPGAP guideline in Annex 2 of this document and FAO International Code of Conduct on the Distribution and Use of Pesticides. No N/A. | Req |
| 8.2.4 | Is a current list of all products that are used and approved for use on crops being grown, kept? | There is available an up to date documented list of all commercial brands of crop protection products that are used and officially registered for use on crops being currently grown on farm and which have been grown within the last 12 months. No N/A. | Req |
| 8.2.5 | Does this list take account of any changes in crop protection products legislation? | The up to date documented list of all commercial brands of crop protection products that are used and officially registered for use on crops being currently grown on farm and which have been grown within the last 12 months has incorporated all the latest changes in crop protection products legislation re crop approvals, harvest intervals etc. No N/A. | Req |
| 8.2.6 | Is the grower informed of restrictions on certain chemicals in individual countries where his products are being sold ? | The grower or the person technically responsible for the crops, can demonstrate via documentation the specific chemical product restrictions in individual countries (e.g. EC Prohibition Directive List – 79/117/EEC and amendments). No N/A. | Req |

While the requirements for farmers within the Fruit and Vegetables Standard is restricted to the use of methyl bromide under the international agreements contained in the Montreal Protocol, the EurepGAP Standard for Flower and Ornamentals does not allow the use after 2004 ("Minor Must"). Overall EurepGAP sets the awareness via its rules to all farmers world-wide and encourages continuous improvements.

## MORE THAN CERTIFICATION

Private sector standard setting and assurance of compliance have been EurepGAP's main activities. However, the example of MB can demonstrate the system of roles and interfaces which determine the success factors for EurepGAP's performance in achieving its holistic objectives (Figure 1). The specific objective is to reduce the use of MB on a global perspective especially for soil fumigation.

### *Compliance with existing legislation*

The GAP rules are set in partnership with the supply chain, including public sector legislation and aspects of continuous improvements. Compliance with these rules is established and checked via a mixture of controls, particularly private sector ISO accredited certification. Any private sector certification should be accompanied by some distinct public sector legislative enforcement .

***Farmer over achievement***

While farmers can already demonstrate their compliance with the EurepGAP standard via the certificate and a central EurepGAP database record, any over compliance which is additional and voluntary is not yet visible to other food chain partners. This lack of transparency will be solved in 2004 by introducing a database where farmers can register all their pest control applications including the use of alternatives to MB. A unique Area ID, based upon GPS (Global Positioning System ) will allow the unique identification and location of each field verified by the certification body. Public sector status reports could be complemented and supported by statistics from this database.

In order to objectively access and measure improvements and identify “over achievement”, a list of available and feasible alternatives and their environmental evaluation must be available for farms to choose from Certification Bodies to judge and customers to value. Public research results may be tailored to their demand.

## SUMMARY

Overall EurepGAP sets the awareness via its rules and controls to all farms world wide and encourages continuous improvement via establishing transparency in the chain. The tools are there, and with a strengthening of interfaces with the public sector via strategic alliances, the positive implications of the EurepGAP private sector approach could be leveraged.

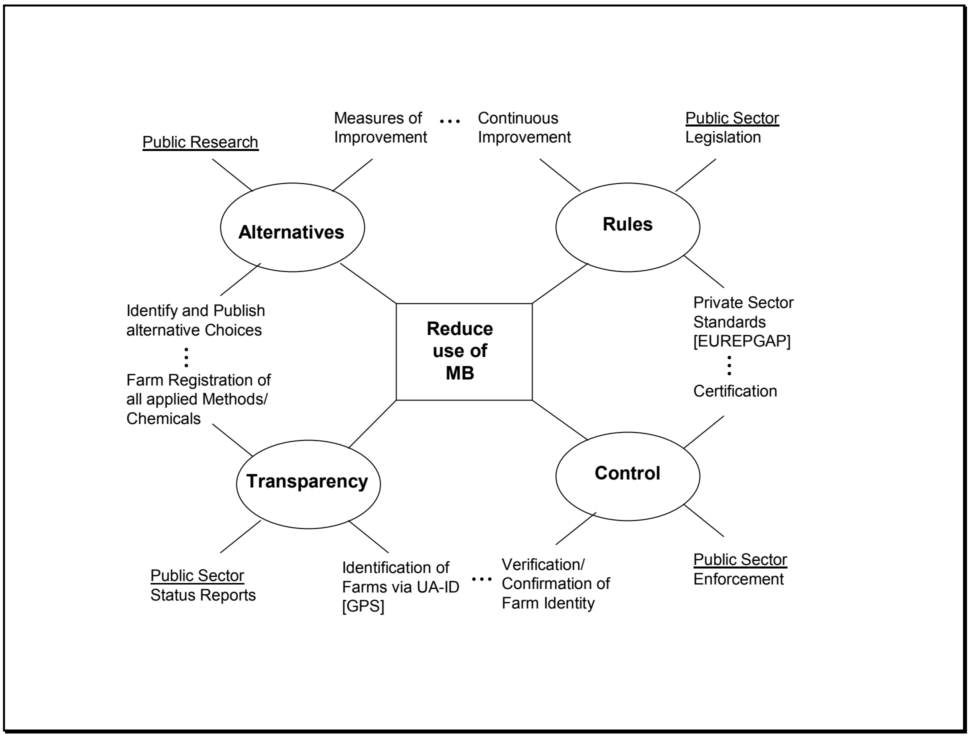


Figure 1: Private-Public Interfaces to reduce methyl bromide

# INDUSTRY-GOVERNMENT PARTNERSHIP FOR THE RAPID REGISTRATION OF ALTERNATIVES TO METHYL BROMIDE — UPDATE OF RESULTS IN THE UNITED STATES

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## ABSTRACT

IR-4's mission is to provide safe and effective viable crop protection alternatives to methyl bromide (MB) to growers of high value specialty crops in the US. IR-4 has partnerships with the US crop protection industry, with the USDA and Land Grant University scientists, and with US EPA and US state regulatory agencies. Candidate alternatives are tested in IR-4 trials, funded by grants from commodity associations and crop protection companies. Depending on importance of the crop to the State, field trials have been conducted on strawberries, tomatoes, cut-flowers and ornamental bulbs, peppers, eggplant, cucumber, cantaloupe, summer and winter squash, and turf. Six products are considered immediate replacements for MB/PIC under specific conditions, pending further work to evaluate their economic feasibility under commercial use conditions. A further six that can be used alone or in combination are not yet registered but have a commercial potential. Finally, three products require extensive field testing to optimize their biological performance prior to recommending them as potential MB alternatives. The progress on these 15 products is reported in the paper.

## INTRODUCTION

IR-4 has been actively involved in trialing crop protection products that have potential as alternatives to methyl bromide (MB) since autumn 1998. IR-4's mission is to provide safe and effective viable crop protection products to growers of high value specialty crops in the US. Because the management of pests that MB controls is so critically important to US producers of specialty crops, IR-4 gave high priority to the research and development of pest management alternatives for MB and MB/chloropicrin combinations (MC/PIC).

IR-4 is in a uniquely favorable position to bring forward viable MB alternatives through its ongoing partnerships with the US crop protection industry, its close association with USDA and Land Grant University scientists, and the excellent working relationship with US EPA and state regulatory agencies like CDPR (California Department of Pesticide Regulation). IR-4 Headquarters personnel meet on a regular basis with companies and learn first hand about products that could serve as replacements for MB. Potential alternatives are allowed to participate in the IR-4 trials, which are funded completely by grants from commodity associations and crop protection companies.

IR-4 research trials are very comprehensive. Experimental products are compared directly to the MB/chloropicrin combination and untreated control (UTC). Trials include complete commercial harvest with the collection of crop yield and crop quality data in addition to pest control evaluations. This comprehensive methodology makes possible obtaining economic data for the MB replacement candidates. Products that show promise as MB replacements in IR-4 research often obtain expedited regulatory reviews through US EPA, potentially saving the registrant two years or more in product registration time. These products, once classified as official "MB Alternative" by US EPA are eligible for simultaneous data review in California. This is quite important since it saves time bringing products to growers in California, a proportionally large user of MB.

IR-4 has short-, intermediate-, and long-term goals. Short term goals involve the testing of EPA-registered products that can serve as immediate replacements for MB/PIC under specific conditions and to determine their economic feasibility under commercial use conditions. Intermediate-term goals involve products and product combinations with products not yet registered but with a clear commercialization path. Long-term goals involve products that are clearly experimental and in need of extensive field testing to optimize their biological performance prior to recommending them as potential MB alternatives.

## IR-4 FIELD PROGRAMS

Large-scale field trials have been run in California and in Florida on strawberries and fresh market tomatoes each year beginning in 1998 (2 trials on both crops in each state or 8 trials total per year). The IR-4 Methyl Bromide Alternatives (MBA) programme was expanded in 2000 to include cut flowers and ornamental bulb crops in California and in Florida, and expanded further in 2002 to include a number of specialty crops in states outside of California and Florida. These areas and the specialty crops included peppers, tomatoes, eggplant, cucumber, cantaloupe, summer and winter squash in Michigan, tomatoes, peppers, and cantaloupe in Florida, tomatoes and cantaloupe in North Carolina, and tomatoes, peppers, cantaloupe, and turf in Alabama. Products and product combinations evaluated as possible MB alternatives to meet short, intermediate and long-term goals and the regulatory status as a result of these goals are discussed below for each product and product combination.

**NOTE:** All statements below concerning the alternatives evaluated in the IR-4 MBA programme are based solely on technical feasibility. Economic analyses of the various treatments were not done and, therefore the economic viability of the treatments is unknown at this time.

### Short-Term Goals Utilizing EPA-Registered Products

Telone/InLine (1,3-dichloropropene + chloropicrin): These products have consistently provided results equivalent to the MB/PIC standard in most crop production systems where weed pressure has been low, but they must often be coupled with a weed control partner to be fully effective. Combinations that have been equal in performance to MB/PIC include either shank injections of Telone C35 or drip applications of InLine followed 5-7 days later with drip applications of either Vapam HL (metam sodium) or K-Pam HL (metam potassium). These combinations need additional research on hillside plantings of strawberries in California where drip applications do not perform well. Recent regulatory actions significantly improving the utility of these products include reducing the 300 foot buffer zone (≈ 91 m) to 100 feet, fewer personal protective equipment requirements for applicators, and the expansion of township caps in California.

Vapam HL/ K-Pam HL (metam sodium/metam potassium): Research has led to a better understanding of optimal conditions for performance from metam sodium/metam potassium. If applied under optimum conditions (good soil tilth and soil moisture prior to application), these products frequently perform as well as MB/PIC as stand alone products. However, the greatest consistency of performance has been obtained in IR-4 programmes when Telone/InLine or Cloropicrin EC in bed treatments are followed 5-7 days later with drip application of metam sodium or metam potassium.

Chloropicrin: In areas where fungal pathogens and weeds are the primary pest problems, chloropicrin, either shank injected or drip applied in beds followed 5-7 days later by drip applications of Vapam HL or K-Pam HL, has been excellent providing results comparable to the MB/PIC standard in most trials. More research is needed on hillside plantings of strawberries in California where drip applications do not perform well.

Envoke Herbicide (trifloxysulfuron sodium): This product controls *Cyperus* spp. (both yellow and purple nutsedges) and as a consequence of having MB alternative regulatory status was EPA-registered for use in tomatoes in Florida and Georgia on a fast track basis.

Sandea Herbicide (halosulfuron methyl): This is another product registered on a high priority basis for use in tomatoes, peppers and cucurbit vegetables for control of *Cyperus* spp. and other weeds.

Propylene Oxide: Propylene oxide (PPO) is registered for the protection of the stored agricultural commodities, nutmeats, cocoa, and spices. Through collaborative efforts between IR-4, the registrant, and the US EPA, post harvest uses have been expanded to include in-shell nuts and cocoa beans, as well as a new product registration involving an 8% PPO mix with 92% carbon dioxide for the treatment of stored nuts. Other label amendments to improve the efficacy of PPO post harvest are pending EPA acceptance. This product also shows promise as a soil fumigant frequently performing as well as the MB/PIC standard at rates greater than 45 US gallons/acre (≈ 350 l/ha) (either shank injected or when applied through drip tapes.

**Intermediate-Term Goals/ MB Replacement Products Pending EPA-Registration**

Basamid (Dazomet): This product was given fast track regulatory status as a MB alternative and it is pending final regulatory decisions. It performs well as a weed control component in combination treatments when used on bed tops following shank injections of Telone C35 or Chloropicrin.

Fosthiazate: Fosthiazate is a specific nematicide and it must be used with other products effective against phytopathogenic fungi and weeds to control the pest control spectrum of MB/PIC. It was registered by EPA in 2004 for use in tomatoes but it will not be distributed to growers until some labeling issues are resolved.

Midas (iodomethane): Iodomethane alone or in combination with chloropicrin (50:50 or 33:67 mixes of iodomethane: chloropicrin) has performed as well as MB/PIC in IR-4 trials when used at rates of 250 lbs ai/ acre ( ≈ 285 kg/ha) or higher in most trials. Products containing iodomethane can serve as technical "drop in" replacements for MB in strawberries, tomatoes, peppers, and other specialty crops. This previously unregistered active ingredient is under expedited data review by US EPA. Registrations are anticipated in 2004 or 2005.

MULTIGUARD™PROTECT (furfural): Greenhouse use of this product on non-food crops for control of nematodes, fungal pathogens, and some weeds is pending US EPA acceptance and it should be registered in 2004. Label amendments to include other non-food crops including turf and field grown flowers, other ornamentals, and food crops not to be harvested within 12 months following application will follow the greenhouse use registration. Agriguard Company LLC, the registrant, plans to file for food crop uses in a third phase regulatory schedule. Furfural (Crop Guard™) is registered for control of nematodes and fungal pathogens in a number of food and non-food crops in South Africa. Registrations are pending in Spain. A unique quality of furfural is that it can be used post transplant for nematode and plant disease control without causing unacceptable phytotoxicity. For full spectrum pest control equal to MB/PIC, it should be combined with metam sodium/metam potassium.

Propylene Oxide: Post harvest label amendments pending US EPA acceptance include an extended period of treatment for spices for improved efficacy. ABERCO, the registrant, is working in collaboration with IR-4 and US EPA to expand the label to include post harvest use to protect dried fruit and nuts in storage. This product controls *Salmonella* which makes it ideal to address the recent almond recall situation in California (17 million pounds (≈ 7,700 tonnes) re-called due to *Salmonella* contamination concerns). US EPA is registering on a fast track an 8% PPO: 92% carbon dioxide mix which renders the active ingredient non-flammable and making it a true MB alternative. PPO will be useful for control of, and protection against *Salmonella*, stored insect and other commodity storage pests affecting nutmeats, in-shell nuts, cocoa, cocoa beans and spices.

SEP-100 (Sodium Azide): The registrant, American Pacific Corporation, has filed for a registration on non-food crops with plans to expand into other crops in a second phase regulatory strategy. SEP-100 has been evaluated in IR-4 trials with mixed results. IR-4 has obtained excellent results from SEP-100 comparable to MB/PIC in some trials and as a consequence it is included in all IR-4 trials in 2004.

**Products Newly Entered Into the IR-4 MB Alternatives Programmes**

Sulfentrazone Herbicide: This product from FMC Corporation has shown excellent promise as a weed control product for strawberries and other crops. It has been included in all IR-4 2004 trials for evaluations in combinations with chloropicrin for control of fungal pathogens and with F3825 200 CS (see below).

F3825 200 200CS: This product is a specific nematicide included in the IR-4 MB Alternatives Programme for the first time in 2004. Based on data from the sponsoring company, FMC Corporation, good control of plant parasitic nematodes is anticipated. Like chloropicrin, it must be "partnered" with products that control fungal pathogens and weeds.

STAN Products: These are seed treatment products that have the potential of protecting germinating seedlings from early invasions from nematodes and plant diseases. The STAN products are being evaluated by IR-4 in several different combinations that utilize Syngenta Crop Protection products (s-metolachlor; fosthiazate, and trifloxysulfuron sodium).

**Experimental Products Evaluated but Dropped from Further Testing by IR-4**

Products extensively evaluated by IR-4 but dropped from further testing by IR-4 due to company decisions to bring the research back into the companies for use refinement include AJ1629 from Ajay, North America, Enzone from Helena Chemicals, and MCC-A1641 from Uniroyal Chemical.

# THE IMPORTANCE OF LEADERSHIP AND INNOVATIVE ACTIVITIES FOR THE SUCCESSFUL IMPLEMENTATION OF THE MONTREAL PROTOCOL

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## ABSTRACT

The Montreal Protocol's Technology and Economic Assessment Panel (TEAP) and its Technical Options Committees (TOCs), including the Methyl Bromide Technical Options Committee (MBTOC), have been instrumental in providing technical information to the Parties of the Montreal Protocol that has enabled them to decide on the appropriate reduction and phase out steps for ozone depleting substances (ODS). The commercial introduction of alternatives to ODS can be seen to pass through a circle of rejection, development and acceptance. Innovative activities and leadership are crucial to the phase-out of ODS including methyl bromide (MB). Although alternatives to MB have been well-documented by MBTOC and TEAP, additional innovative activities and leadership are required to reduce the amount of MB requested in the future for critical use exemptions. Such prompt action may reduce the cost of the transition to MB alternatives and reward the suppliers of environmentally superior technology.

**Keywords**: assessment, innovation, leadership, methyl bromide, Montreal Protocol, ozone depleting substance (ODS), TEAP, Technical Options Committee (TOC)

## THE ROLE OF TEAP AND ITS SUBSIDIARY BODIES

Directly after the Montreal Protocol was signed in 1987, the Parties to the Protocol recognised that they would need advice from independent experts organised into assessment bodies. At their first Meeting, they formally installed Assessment Panels, which were instructed to update the Parties via regular assessments of latest scientific, environmental and technical and economic progress related to developments to halt further ozone layer depletion.

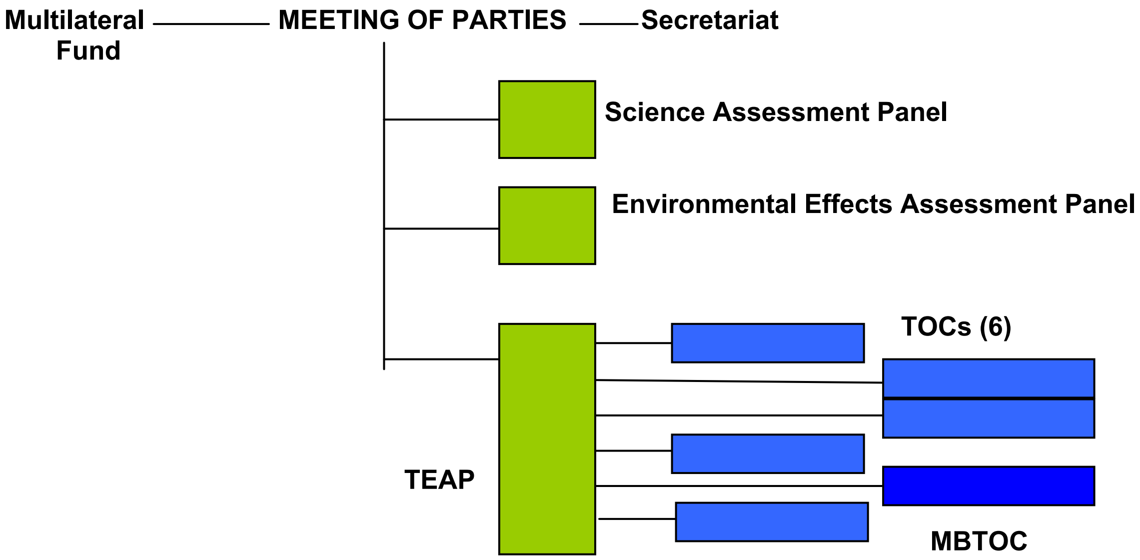
The Scientific Assessment Panel (SAP) and the Environmental Effects Assessment Panel (EEAP) organised experts into "chapters" to cover relevant topics. The Technology and Economic Assessment Panel (TEAP) organised its work assisted by five technical subsidiary bodies, called Technical Options Committees (TOCs), spanning the range of ODS applications: aerosol products, foams, halons, refrigeration and solvents/ chemical uses. This has now been expanded to six TOCs including methyl bromide (MB). The structure of TEAP and the TOCs in relation to Parties is shown in Figure 1.

The first Assessments were conducted by all Panels in 1989 and 1991, on the basis of which Parties decided a phase-out of many ODS by January 1996 (or earlier) at their Meeting in Copenhagen in 1992. At that time, a first science-technology report was published and presented on MB, its damage to the ozone layer and feasible actions to minimise and eliminate this impact at short notice. As a consequence of Decisions by Parties to control MB, the Methyl Bromide Technical Options Committee (MBTOC) was established in 1993, to regularly assess the technology for replacing MB.

The TEAP and its TOCs publish an annual progress update, respond to the requests for information by the Montreal Protocol Parties on an annual or biannual basis, and carry out a full assessment every four years, which is integrated with the findings of the SAP and EEAP. The TOCs report though the TEAP to the Parties, via the Report of the TEAP. Very specific requests by Parties will normally be handled by a Task Force, chaired by one or two TEAP members, with membership from TEAP and TOCs, as well as from outside experts.

The TEAP consists of three co-chairs, the co-chairs (normally from a developed and a developing country) of the respective TOCs and a number of Senior Expert Members. At this moment the TEAP has fifteen members and is planning to increase its membership at short notice.

Figure 1: Relation of the Technology and Economic Assessment Panel and its Technical Options Committees to the Parties of the Montreal Protocol




### THE CIRCLE OF REJECTION, DEVELOPMENT AND ACCEPTANCE

Even after the theory was accepted that ozone depleting substances (ODS) are the direct cause of ozone depletion world-wide, the commercial introduction of alternatives and substitutes usually involved three distinguishable phases: (1) Rejection; (2) Development and performance validation; and (3) Acceptance and celebration of replacements

**Rejection**: In the first phase, users and producers of the conventional ozone depleting product tend to be sceptical and defensive, challenge the precise environmental damage that is caused by the use of their ODS, listing and repeating the advantages of the old ODS technology, forecasting technical and regulatory hurdles that cannot be overcome and predicting serious economic disruption if technology is changed. Defenders of ODS often claim that the problem of substitution is too complex, and that any alternative will surely have similar or comparable environmental consequences to the original ODS.

**Development**: At a certain stage industries move beyond rejection and scepticism and switch their attention to the rapid development of alternatives, including extensive performance and toxicity testing. If the burden of the development of alternatives can be shared via industry consortiums, the development will take place at an accelerated pace. The development may be stimulated by consumer awareness and market rewards or by the avoidance of environmental prohibitions, taxes and/or reporting. Market transformation becomes irreversible when industry embraces the commercial advantage of alternatives -- either at higher cost and better performance -- and /or if new technology could lead to an increasing market share.

**Acceptance**: Eventually, alternatives are accepted when the economic and environmental performance together outweighs the earlier substance. It may also imply that the costs for the consumer or user will increase, albeit for a higher quality environmentally better product. Once the new technology or substitute has been introduced, further optimisation of the product opens new ways and means for new applications that are superior to the first generation alternative technology.

Some examples of ODS and alternatives cycling through the cycle of rejection, development and acceptance:

*One third of global CFC production was for aerosol cans in 1986/87*

Consumer awareness that CFC aerosol products were depleting the ozone layer had an impact on companies, which had to improve their environmental profile. Consumer boycotts and product prohibitions accelerated development. The hydrocarbon alternatives that were already on the market out-competed the more expensive and disparaged CFC products with rapid market transformation. Final acceptance normally takes place once the product has been developed, financial support for conversion has been secured and export markets for the product have been identified.

*The emergence of HCFCs and HFCs in refrigeration in 1989/1990*

Although the refrigeration industry accepted the fact that HCFCs were listed as transitional substances under the Montreal Protocol, they were seen as the primary replacements for CFCs with the advantage of a relatively small ozone depletion potential. They were cheaper, were already developed and commercialised (as in the case of HCFC-22) and were stated to perform better, in particular in air conditioning apparatus and supermarket cooling. Industry, however, continued the development of HFCs and HFC mixtures, which were really accepted by the refrigeration industry in the developed countries once it became clear that HCFCs would eventually be phased out.

*The replacement of HFC-134a by hydrocarbons in refrigerators in 1992/94*

Although refrigerator manufacturers had developed their circuits for HFC-134a, pressure by NGOs stating that HFC-134a was not the really sustainable solution led to heated discussions regarding the energy efficiency of a hydrocarbon refrigerator. Eventually, consumer and NGO pressure, as well as competition between German manufacturers, initiated the large-scale development of hydrocarbon based refrigerators, with hydrocarbons in both the circuit and the foam. Both manufacturers and consumers accepted the final "green" product which had at last a similar performance and also opened the possibility to further enhance the efficiency of the hermetic compressors.

In many cases, the use of a new non-ODS chemical required the development of a modified, adjusted or completely new product. In some cases, the new chemical cost more than the ODS it replaced, but the chemical was such a small portion of the final product price that it was economically unimportant. For example, refrigerant HFC-134a costs 3-5 times more than the CFC-12 it replaces in refrigerators, but the total cost of the new chemical is still less than 0.1% of the consumer price of the entire product.

T*he phase-out of halons was much earlier than expected*

Being already an important issue at the time of the signing of the Protocol because of their extremely high ozone depleting potentials, it was expected that the phase-out of halons would take a large number of years, particularly for high-technology and military applications. Companies started the development of alternatives, but alternatives were not accepted until military and petrochemical leaders embraced ozone layer protection and switched their standards to non-halon based extinguishing. This opened the way to phase out halons in 1994, while maintaining a bank of halons already produced before 1994, for critical uses only.

## LIST OF INNOVATIVE ACTIVITIES THAT HAVE LEAD TO REDUCTIONS IN ODS USE

Rather than present a long narrative on the possible impact of innovative activities, some examples are given below:

- Teams of experts assembled to find globally-valid solutions and this has avoided the exemption for many laboratory and analytical uses of CFCs which could have expanded enormously;
- The taxing of CFCs after the phase-out (as e.g. in Singapore and the USA) accelerated the

phase-out and shortened the prolonged use of CFCs in many cases;

- UNEP's anti-dumping activities in developing countries avoided ODS-equipment being shifted from developed to developing countries, with the added consequence that it would have been retrofitted or replaced at the cost of the Multilateral Fund and its developed country contributors;
- Public activities undertaken by large companies in electronics and semi-conductors have risen public awareness, developed promoted new "no-clean" technologies in the companies, and resulted in a rapid phase-out of CFCs in those industries;
- Although promoted by the environmental non governmental organisation (ENGO) Greenpeace, the development of hydrocarbons for refrigerators and hydrocarbons and carbon dioxide has led to innovative corporate activities that have shed a new light on the future application of the different fluorocarbon chemicals;

## ROLE OF LEADERSHIP IN THE REPLACEMENT OF ODS

Leadership has been very important in the phase-out of CFCs and halons and is still important for the success of the Montreal Protocol. Corporate leadership is a trademark of the Montreal Protocol - business support for phase out has been important through technology co-operation and collaboration. Some examples where acting locally has stimulated phase out globally are:

- The electronics and semiconductor industry in the early 1990's promoted the phase out CFCs faster than required by the Montreal Protocol;
- Companies promoted a conversion to non-fluorocarbons in domestic refrigerators in 1993, vehicle air conditioning in 1994, beverage and food companies first in 1995 and now in 2004;
- Certain government or regional regulations in Europe and some states in the USA were more stringent than the Montreal Protocol;
- The US EPA honoured individuals and corporations with the US EPA Stratospheric Protection Award since 1990 and thereby stimulated further progress and leadership. Twenty individuals and 9 companies and teams in the last five years have received the EPA award in the last 5 years for leadership on alternatives to MB.

## METHYL BROMIDE ASSESSMENTS

The first assessment of MB use and emissions was published in 1992, concluding that MB had an ODP of 0.7 which was comparable to methyl chloroform, an ODS already controlled and scheduled for phase-out. At that time, it was estimated that MB emissions would deplete the ozone layer when it would be is at its most fragile state due to depletion from CFCs and other substances. In 1997, ten years after the Montreal Protocol was signed, a MB control schedule for developed counties was established with a phase-out by 1 January 2005.

This phase-out decision was supported by Scientific, Environmental Effects and Technology and Economics Assessments in 1998 and 2002, and in particular, by assessments by the MBTOC in 1998 and 2002. In the latter two assessment reports alternatives for soil fumigation were dealt with where the relevant chapter had about 280 and 320 technical references, respectively; the chapter on post-harvest had about 320 and 370 references in 1998 and 2002, respectively. Also in the years between the full assessment years, the MBTOC reported on progress in the field of alternatives, with a chapter in 2004 consisting of 24 pages with about 130 references. It was also supported by the growing experience with eliminating MB from a wide variety of uses.

Nevertheless, many users of MB argued against the MB phase-out due to different interests in different parts of the world. Public awareness that had been centered on consumer products and manufacturing and had never focused on MB use in the 1990s and by 2000. Many of the ENGOs involved were less active and less funded.

The use of MB is comparable to the use of solvents in product manufacturing. However, in the solvent sector globally operating companies provided leadership, whereas in the MB sector only few global companies choose to make stratospheric ozone protection a market priority.

Cost increases in the case of the application of alternatives (although comparable to the cost of alternative solvents) are seen by MB users as different because they are paid by local users, not by global companies or their customers. Nevertheless, MB forms a small portion of the total on-farm cost of producing a crop and this crop production cost is often a small portion of the price paid by the final consumer.

Companies marketing ODS substitutes concluded co-operative agreements and could market innovative technology around the world. However, as MB substitutes have to be demonstrated under local circumstances they need local registration which often takes a long time.

Many governments decided on prompt global regulations to phase-out CFCs and other ODS by implementing more stringent regulations than the Montreal Protocol. However, the same action has not taken place for MB. Only the Netherlands and a small number of developing countries have aggressively phased out MB. In The Netherlands, the phase-out was stimulated by toxicity concerns, not ozone depletion. In many cases, continued use of MB is defended by governments since the alternatives registration is a cumbersome process and the agricultural business is seen as totally different from the markets and applications where ODS were used. This difference in perspective lead to the endorsement of the critical use exemption (CUE) process, which, in fact, is comparable to the essential use process under the Montreal Protocol, but absent the essential use criteria that the application is "necessary for the health, safety or is critical for the functioning of society (encompassing cultural and intellectual aspects)" (Decision IV/25, I (a)(i)).

## METHYL BROMIDE - CRITICAL USES AND ALTERNATIVES

Despite a continued apparent commitment to phase out, CUEs for the use of MB in 2005 have been requested by the EC (10 Member States), Australia, Canada, Israel, Japan, New Zealand, Switzerland and the USA (Hildebrand 2004). CUEs requested by the USA alone exceed the requests from all the other countries combined. USA and EC requests for CUEs for 2005 constitute about 38% and 18% of their 1991 base levels respectively, instead of the phase-out as originally agreed.

In the absence of actions at the Protocol or government level to limit CUE applications, requests may well continue for a considerable time. MBTOC will recommend CUEs on technical grounds, mainly associated with the lack of registration of alternatives. However, some governments seem to have "fast track" processes for the registration of alternatives, but they are still protracted, expensive and exhaustive. The registration of an alternative is costly, time-consuming and data intensive. The cost-benefit can be marginal given a total MB replacement market of about 50,000 tonnes of MB world-wide for non quarantine and pre-shipment (QPS) uses. The market is fragmented which requires separate registration applications on a country-by-country basis.

Only a few countries have so far systems in place that increase the price of MB to improve the competitiveness of alternatives. In most cases, it has been left to market forces to introduce alternatives in the MB sector. However, Europe is proactive and now seems to be developing its own regulatory system to minimise MB use.

As to the leadership in the alternative sector, there are a number of prominent examples. These include the promotors of methyl iodide, 1,3-dichloropropene and azide in the soils sector; and of phosphine formulations, sulfuryl fluoride and ethyl formate in the post-harvest area. Without this independent work the prospects of reducing the amounts for CUEs would not be positive. The amounts of MB already approved for critical uses, and expected to be approved in 2004 for critical uses in 2005 and beyond, are likely to form a major setback for those companies, who had invested in alternatives.

## LEADERSHIP AND INNOVATION NECESSARY FOR REPLACING MB IN CRITICAL USES

This following steps would encourage the elimination of MB for critical uses.

1. Companies involved in MB production and distribution should ensure long term sustainability by being involved in the production, testing and distribution of alternatives;
2. User associations should increase global technology co-operation in order to exchange experiences, set up databases on which alternatives can be used where and bring forward case studies on alternatives for assessment by the MBTOC;
3. Part of an awareness campaign should be to train growers on the use of alternatives. Experienced growers should train following the "train the trainer" approach. Field visits should be an integral part of this training;
4. International product labelling should empower consumers with information necessary to make a choice. Crops produced with MB are already disqualified in many countries from programmes labelled 'organic'. Multinational food service companies that were instrumental in the CFC phase-out can also have a greater leadership role on MB alternatives;
5. Registration of alternatives should be co-ordinated by governments, both regionally and internationally; and
6. Funding schedules to initiate a transfer to alternatives should be considered. Agricultural subsidies should be used to reward users that use non-ODS treatments;

## CONCLUSIONS

A large number of the activities that were successful in phasing out CFCs and other ODS can be incorporated in strategies that will increase the competitive advantage of alternatives which will outperform MB. With such strategy in place, MB users will also realise that there will be financial consequences for those last to adopt new practices. The lessons from the ODS phase-out and the advice in going from toxic and ozone depleting MB to strategic pest control could be "Act before others act for you!"

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**Disclaimer**: This paper presents the personal perspectives of the authors who are the co-chairs of the TEAP, but does not necessarily present the views of the organisations where they are employed, of UNEP or the TEAP.

# INTERNATIONAL AND NATIONAL POLICIES THAT HAVE PROMOTED THE REDUCTION AND PHASE-OUT OF METHYL BROMIDE

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## ABSTRACT

More than 150 countries have ratified at national level the sections of the Montreal Protocol that require methyl bromide (MB) to be phased out. Official data on methyl bromide (MB) consumption indicates that many countries have made substantial progress in phasing out MB. Countries normally regulate the consumption (national supply) of MB by limiting the quantity of MB that can be imported. During the phase-out of other ozone-depleting substances (ODS) such regulations have often been augmented by non-regulatory activities to assist ODS users in converting their operations to ODS-free methods. Based on experiences in various countries, this paper identifies activities that have assisted MB users in their phase-out efforts. Montreal Protocol projects in developing countries have shown that technology transfer and technical training normally play a very important role. Other useful activities include the provision of information resources, use of economic signals, encouragement for companies to review their policies and contracts, and the development of new industries to provide alternative products and services in rural areas.

## INTERNATIONAL MEASURES

The Montreal Protocol's Multilateral Fund (MLF) provides resources for assisting developing countries to phase-out MB. The MLF has approved more than 40 projects that are designed to achieve early phase-out of MB, by helping farms to install alternative equipment and products, and training farmers how to use alternatives effectively. Experience has shown that projects can train thousands of farmers in a relatively short period. Argentina, for example, established a well-organised programme which trained more than 2,700 farmers in the first year of a national project, and will continue to train further thousands until the entire sector has adopted alternatives (Valeiro 2002). Many of the recently-trained farmers in Argentina are very poor and uneducated, having few resources. It is notable that many were able to adopt successfully an alternative system based on substrates (floating tray system) which requires many new skills compared to the traditional MB application method. The transfer of existing alternatives from other countries has enabled a number of developing countries to achieve rapid reductions in their use of MB.

## NATIONAL PROGRAMMES

Some countries established national plans or programmes for MB phase-out, such as the Netherlands, Australia, China, the Philippines and Thailand. Developing countries often developed such plans as a component of MLF projects. These plans identified factors such as:

- Necessary amendments to national regulations on pesticides, ODS and/or import of controlled substances
- Programme for identifying suitable alternatives and/or transferring them from other regions
- Programme of training and technical assistance for fumigators and MB users
- Timetable for MB reduction steps
- Responsibilities of government departments and stakeholder groups

The Netherlands, for example, implemented a national programme in the 1980s. The horticultural sector relied heavily on MB in the 1970s, using about 3000 tonnes MB per year. But as a result of various MB fumigation accidents, water pollution and MB air contamination close to residential areas, the government carried out a review of MB uses and alternative options (Lower House 1981, RIVM 1980). They decided to phase-out use of MB in soil fumigation, and carried out the following activities (Lower House 1981, van Haasteren 1994, International workshop 1992):

- Identification of suitable alternatives; further development as required
- De-registration of MB for uses where alternatives became available

- Permits required for each MB fumigation, issued by pesticide authorities, case by case, based on evidence of soil-borne pests and genuine lack of alternatives
- Fumigation sheets were required on soil for 10 days
- Increased safety restrictions, eg. larger buffer zones
- Technical assistance to help farms adopt alternatives
- Industry – government cooperation

## ECONOMIC SIGNALS

### Levies and taxes for promoting alternatives

Some countries placed levies or taxes on MB or other ODS, as a disincentive for using them. The funds are often used for the promotion of alternatives. From 1995 Australian MB users and importers introduced a levy – a kind of voluntary tax – on MB, to generate funds for trialing alternatives. The levy was collected at wholesale level by the MB importers. The funds were matched by funds from the government, giving about Euro 300,000 per year for the adaptation and improvement of alternative techniques (Porter 2002). The Czech Republic's ozone protection legislation placed duties on imports of MB and other ODS, and the revenue is used by a state Environmental Fund for ozone layer protection (Parliament of the Czech Republic 1995).

### Re-targeting current grants and subsidies

A number of governments currently promote agricultural innovation and exports by providing grants for specific activities. These give important economic signals to farmers and can help determine their choice of pest control methods, including MB or alternatives. The regional government of Ragusa in Sicily, for example, organized a programme in the 1990s to promote new agricultural technologies - they subsidised the purchase of plastic sheets for solarisation (25% of cost reimbursed), and machinery (13% reimbursed) to lay plastic for open-field solarisation. Irrigation systems were also subsidised (Vickers 1995). The EU's Common Agricultural Policy (CAP) has several funding mechanisms that could be used to assist MB users in the adoption of alternatives, such as: grants for investing in farming methods that reduce the polluting effects of agriculture, grants for training in agricultural practices for environmental protection and for vocational training to meet modern requirements. Several rural development programmes provide funds for advisory services, technical assistance and training, demonstration projects and pilot projects (Prospect 1997, Smeets 1998).

### Tax rebates for alternatives

Some governments have reduced the import duties and company taxes for non-ODS alternative equipment and products, to make investment in alternatives more attractive for users. Malaysia and Singapore, for example, granted reductions in company tax for firms who invest in ozone-friendly technologies. India waives customs duties on imports of non-ODS manufacturing equipment (Miller 1999a).

## INFORMATION RESOURCES

### Information about local alternatives

MBTOC, the Montreal Protocol's technical committee on MB, provides reports on existing and potential alternatives; of necessity this information is global in scope. MB users have benefitted from local publications that focus on local MB uses and pests, and relevant alternative pest control methods. In Scandinavia, for example, the Nordic Council assisted MB users in the mid-1990s by publishing information about MB alternatives relevant to that region (Nordic Council 1993, 1995, 1997; Danish EPA 1997). Australian researchers have held many meetings with local groups of growers to identify the most promising MB alternatives, and they publish a regular update for growers about results of regional alternatives trials and demonstrations (Porter 2002).

### Technical 'how to' booklets for users

A number of the MB projects carried out by developing countries (under the MLF) have produced practical booklets or materials for growers in local languages, describing how to apply alternatives correctly for crops such as tomato, pepper, strawberry and tobacco. In the post-harvest area, GTZ has published practical booklets about methods of stored product protection (GTZ 1996), while Agriculture and Agri-Food Canada has produced a useful CD-ROM (Fields et al).

**Lists of companies that supply alternative products and services**

Farmers and other MB users need to know where they can find suppliers of alternative equipment, products and services; lists of companies and suppliers can provide a useful resource (Miller 1997). UNEP published a series of Sourcebooks on suppliers of ODS alternatives for CFCs and halons, as well as MB, listing examples of companies who manufacture and/or supply alternative products and services, and providing contact details. Some of the 'how to' booklets produced in developing countries contain contact details for local suppliers of alternatives.

It would assist European MB users if local bodies were to compile lists of suppliers of products such as alternative fumigants and pesticides, relevant application equipment, cheap substrate materials, sheets for biofumigation or mulch, etc. Lists should include companies/organisations who provide related services such as pest identification, training in IPM and MB alternatives, alternative fumigation services, portable steam treatments, and technical advice on the control of soil-borne pests.

**Brochures about new business opportunities**

The Canadian government has noted that ODS phase-out provides an opportunity to develop new businesses and new industries, at the same time as benefiting the environment (Environment Canada 1996). Some MB projects in developing countries informed local companies about the business opportunities arising from MB phase-out, particularly opportunities for small and medium sized enterprises (SMEs). The national MB project in Argentina, for example, assisted local companies to set up production of seed trays and other inputs, in order to reduce the cost of importing alternatives from other countries. Since most countries import MB, there are opportunities for import substitution and local job creation.

## COMPANY POLICIES AND CERTIFICATION PROGRAMMES

Companies that purchase large volumes of fruit, vegetables and stored products often set conditions or specifications for product quality and other parameters in their contracts with suppliers. Some food manufacturers and supermarkets have played a role in identifying MB alternatives, reviewing their company policies and contracts, eliminating requirements for suppliers to use MB, and actively encouraging the adoption of alternatives.

**Company policies**

Several supermarkets promote integrated pest management programmes, which can have an impact on MB use. For example, Sainsburys in the UK reported that its IPM programme did not permit the use of MB for certain crops, while in other crops MB use was being reduced (MBTOC 2002). Some of Sainsburys' contracts specifically prevent the use of MB by suppliers. The Co-op supermarket organization owns a number of farms in the UK and banned the use of MB as a soil fumigant on these farms in the mid-1990s (Co-op 1996). The Co-op announced in July 2001 a new code of practice developed with its suppliers which will prohibit 24 pesticides including MB, as a result of rising consumer concerns about health and environmental impacts of agriculture (Buffin 2001b). Marks & Spencer announced a plan requiring its suppliers around the world to reduce and phase-out the use of 79 pesticides that pose risks to health or the environment; MB is included in this list (Buffin 2001a).

In Spain, the Association of Harvesters and Exporters of Fruit and Vegetables in Almería (COEXPHAL) has had 25 years of experience in intensive horticulture in the south-eastern part of Spain. From 1997 growers were requested not to use MB as a policy of the Association, and today MB is no longer necessary for production (Fernández 2002).

**Environmental certification programmes**

Industry environmental standards and certification programmes have assisted the adoption of MB alternatives. For example, an international environmental certification programme for cut flowers, called MPS, sets standards whereby farmers reduce their use of pesticides, fertilizers, water and energy. MB cannot normally be used in the production of MPS grade flowers. More than 5,000 farmers implement the MPS programme in 22 countries including the Netherlands, Belgium, Italy, France, USA, Israel, Kenya, Zimbabwe, Zambia, Costa Rica and Ecuador (de Groot 2002). The EUREP-GAP standards of good agricultural practice, established by a group of European supermarkets, also promote the production of crops without the use of MB (Moeller 2002).

**Consumer information**

Information on labels can inform users and consumers of ODS about the problem of ozone depletion, raising their awareness. Under the US Clean Air Act, for example, containers of ODS are required to carry a special label which reads: 'Warning: product contains [name of ODS] a substance which harms public health and environment by destroying ozone in the upper atmosphere' (Clean Air Act section 611). TEAP, an advisory body to the Montreal Protocol, reviewed the role of environmental labelling and concluded that 'The purchasing decisions of consumers can also be influenced by product information… Those Parties [countries] that are not yet using eco-labelling systems to promote the objectives of the Montreal Protocol might consider the benefits of adding such a market-based measure to their ozone protection policies.' (TEAP 1997).

In the case of MB, some consumer and environmental organisations have requested labelling of products grown with or without MB so that consumers will be able to exercise a choice when they purchase fruit and vegetables (MBTOC 2002). An agricultural project in Jordan developed a certified label for products grown without the use of MB, as part of an IPM programme. The labels were trialled on packs of fresh strawberries exported to supermarkets in Europe. The retailer gave positive feedback and encouraged the producer to continue labelling products in this way (Hasse 2001, MBTOC 2002).

**Company leadership in the commercialisation of alternatives**

TEAP has highlighted the important role of companies who decide to take a leadership role in the development and commercialisation of non-ODS alternative products and services (TEAP 1997). In the mid-1990s in the USA, for example, Fumigation Service and Supply Inc, a fumigation company that used large volumes of MB, took the lead in trials and commercial adoption of alternatives for commodities and structures such as food processing plants and flour mills (MBTOC 1998, Mueller 1998). In Peterborough Canada, Quaker Oats food processing plant developed innovative and effective pest control system based on sanitation, IPM and heat treatments (Health Canada 1998, Environment Canada 1995).

Some countries have encouraged companies to take a leadership role in the commercialisation of ODS alternatives by establishing awards to recognize their efforts. The Environmental Protection Authority in China, for example, organises annual awards for companies and individuals who show notable leadership in ozone layer protection (SEPA 2004).

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# EFFECTIVE TECHNOLOGY TRANSFER METHODS FOR ADOPTION OF METHYL BROMIDE ALTERNATIVES IN THE SOIL SECTOR IN PROJECTS FUNDED BY THE MONTREAL PROTOCOL: THE CASE OF ARGENTINA

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## ABSTRACT

Since 1998, a coordinated INTA-UNDP-Ozone Unit methyl bromide (MB) demonstration project has been concluded, and a MB phase out project initiated, in the Argentinian tobacco sector. The project strategy and actions focused on appropriate actions to minimize MB demand and supply. Up to date 55% of the tobacco seedbed area is already using alternatives such as the floating tray system and metam sodium. Approximately 4,600 growers and 180 technicians have been trained in the use of alternatives to MB, and a total of 18,275 growers have received technical assistance on an on-farm basis. To date, the project has shown that it is possible to achieve important reductions in MB consumption in developing countries in a limited period of time. An holistic approach is required including obtaining political support for the strategy and goals, ensuring that stakeholders participate in designing and implementing the strategies, decentralizing the participation and the design of the technical proposals, and ensuring the availability of an adequate funding.

**Keywords**: Methyl bromide, alternatives, tobacco, floating tray system, training, Montreal Protocol, Argentina

## INTRODUCTION

Tobacco is grown in seven Argentine provinces, all of them in the north of the country but with climate varying from tropical/sub-tropical with high rainfall of 1,500 mm per year to a much drier region with about 400 mm per year. The initial tobacco production area was 74,400 ha in 2000. In 2002 the planted area dropped to 67,500 ha, while in 2003 it grew again to 80,545 hectares. The total number of tobacco growers ranges between 24,000 and 25,000 depending on the year.

The provinces show different tobacco production and social structures, varying from many thousands of peasant farmers (almost 80% of the tobacco farms), to family farms and larger commercial farms. The tobacco seedbeds are 70-80 (sometimes 100) square meters in size for each hectare that would be planted.

The 'conventional' application rate for methyl bromide (MB) is 8 one-pound cans for 80 square meters of seedbed ie. 36 g /$m^2$. Tobacco farmers place MB one pound cans (98% MB, 2% chloropicrin) on the seedbed soil and cover it with 80-100 micron clear polyethylene sheets. MB is applied manually by farmers and laborers, by making a hole in the can with a nail at the top of a stick from outside the plastic cover. The tobacco sector's MB consumption in 2000 (when the project was designed) was of 268 tonnes.

The Montreal Protocol's multilateral fund has sponsored projects in Argentina since 1997. The investment project aims to phase out MB consumption in the tobacco sector by 2007. This coordinated INTA-UNDP-Ozone Unit work is presented in this paper.

### Project's work on the supply side - involving the stakeholders

The first criterion agreed was that to eliminate MB it was necessary to approach the project from both the supply (the source of MB) and demand (the growers) viewpoints.

In Argentina 100% of the MB is imported. At the moment of the Project launch, three companies imported and distributed MB. From that point, the distribution scheme passes through cooperatives, provincial governments and tobacco companies that normally loan MB to their associates or clients, or pesticide sellers where the growers buy it.

Knowing this distribution system, a working strategy was designed in two directions. One, on the demand side, consisted of creating a technical team and transferring the new technologies to the growers. While in the other direction, the strategy acted on the suppliers to make MB access more difficult to them, as far as possible. In the latter, almost 40 multi-stakeholder policy dialogue meetings were held with local authorities in all the seven tobacco production provinces, including growers, grower's organizations, tobacco companies, and national governmental agriculture institutions.

The main issues on the agenda included: presentation of the project and its objectives; explanation of the agreement between Argentina's government and the Multilateral Fund of the Montreal Protocol; and, the need to complement the project's resources with in-kind labour and financial resources. The concept transmitted was that eliminating MB was not just because an environmental concern, but also to improve crop productivity and international competitiveness of the national tobacco production.

The need for a specific agreement between INTA and each local government – involving the local tobacco private sector – as a condition for receiving the funds was stressed, and a draft model was designed, discussed and finally signed.

As a consequence of this participation, the execution strategy of the Project and the investment decisions are discussed and decided every year in each province by a Commission composed by representatives of the local government, INTA and the main local tobacco growers' organizations. Only some commissions include representatives of the tobacco companies.

It is true that due to the current tobacco market trends and the stringent conditions being placed on the tobacco sector by their consumer markets, tobacco growers and its industry the world over are being forced to use environmentally-friendly techniques, and this trend renders political support to the project strategy. However, the key was to articulate different interests: the local governments were interested in the funds to be used in their provinces; grower's organizations in seeing their associates being benefited with the subsidies; and the tobacco companies saw the project as an opportunity for accomplishing their own environmental objectives.

As a result of this strategy, the supply sources of MB were dramatically reduced. In 2003 and 2004 neither a provincial government, nor any tobacco company loaned MB to their growers and the vast majority of the growers´ cooperatives no longer do it. Today, a tobacco grower that wants to use MB has to pay a pesticide retailer.

**Work on the demand side - transferring the alternatives**

Regional teams were formed by INTA´s regional expert staff familiar with local agricultural practices and growing conditions that work to provide specific and focused training in alternatives. Besides each regional core team, the Project contracts every year between 30 to 60 temporary extensionists that work for 5 months training growers and giving technical assistance to them in a conventional "training and visits" extension system. In one province (Misiones) the tobacco companies' technical teams closely cooperate in transferring the new technology.

During the first year, an intensive "training of trainers" activity was needed because the floating trays system was new, even for the technicians. The first year's field extension experience, however, was even more important for them to acquire their own know-how.

The average transferring practice consists of:

a. Field training: The production areas are allocated to the extensionists and groups of 10-20 or more growers (depending on the region) are organized for field training in the relevant alternative practices: Preparation and application of floating tray system and metam sodium (including IPM, water/fertilization control, clipping, safe disposal of pond water, tray conservation and adequate storage, economics etc.), as well as information about the problem of ozone depletion and MB. Inputs are also distributed to these growers, according to lists previously approved by the Consultative Committees.

b. Follow-up farm visits: The extensionists make individual visits to the farms following-up the alternative during the season. Water conductivity in each pool is controlled, the results of the crop development are registered, and farmer's consultations are attended. It is considered that each extensionist can make an average of three to four visits per day. Each farmer is visited an average of six to eight times during the seedbed production stage.

During the training period each year, an important publicity campaign is conducted through the communications media, using INTA's expertise in this area. Leaflets, manuals, and other informational materials are produced and distributed in each region.

To date, 4,581 growers and 179 technicians were trained, and a total of 18,275 growers received technical assistance on an on-farm basis.

Of course, the speed of implementation and uptake varies from region to region. For example, in Misiones the small growers (nearly 17,000) easily accept technical changes and new production methods, or are more open to the companies recommendations (probably because they are highly dependant on them). Therefore, the project made excellent progress in this region despite the large challenges involved in training and visiting many small-scale growers. This was possible with the close coordination of the private sector technical teams. In contrast, due to the larger tobacco areas planted by each grower in Salta or Jujuy, they are more independent from the companies and technological innovations required much larger capital investment per farm, making them reluctant to make such investments in a difficult economic environment.

**Achievements up to date**

In reducing sector's MB consumption: The main reduction achievements are presented in the following Table 1.

Table 1: Methyl bromide substituted during 2003 season in the tobacco sector, compared to 2002

| Action | 2002 | 2003 |
|---|---|---|
| Planted area* (ha) | 67,500 | 80,545 |
| Area with MeBr (ha) | 42,755 | 36,256 |
| Area with alternatives (ha) | 24,745 | 44,289 |
| MB use (metric tones)** | 155 | 106.57 |

* Planted area figures are still provisional and unofficial
** It was observed that an average 6.5 one pound cans for 70-80 $m^2$ was used for a seedbed (for planting 1 ha) in 2003

Comparing the sector's initial consumption of 268 tonnes, it was reduced to 155 tonnes in 2002 and 106.57 tonnes in 2003. Even though the 2002 reduction could lie mainly in the decrease of the area (due to the deep economic crisis in the country), the 19% growth in the tobacco planted area during 2003 seedbed season showed a real reduction of 31,24% in MB consumption. This would indicate a good sustainability grade of the reduction.

In achieving sustainability of the technological change:

Regarding the technical sustainability the project is in different phases of addressing:

- The potential of seedling diseases through the polystyrene trays: Testing different chemical disinfectants, and testing and promoting the use of steam in individual or community facilities. Promoting integrated pest management programmes.

- Preventing potential environmental problems: Avoiding pool waste water of polluting water courses; studying different alternatives for the disposal of the old polystyrene trays and testing less polluting materials.

In terms of economic/commercial sustainability the project is:

- Promoting and supporting the national production of trays and substrates. During the project period – also moved by an important devaluation of the national currency - some local companies began producing trays and substrates in sufficient quantity to meet the project needs during 2004 and are competing in the local market.

- However, the project team continues to work with substrate suppliers to develop and test new mixtures according to the tobacco sector needs, and designing specifications and quality control measures to ensure that a sustainable local substrate industry can be developed in the future.

- At the same time, the Project research group developed a new pine bark-based substrate formula, considered to be a more renewable source of raw material than the peat, and a considerably cheaper one. It is estimated that this substrate would be in the market by 2006.

- Testing and promoting the use of non-pelleted seed techniques. Pelleting technology is not available in Argentina, so growers need to import them or even send their own tobacco seed to be pelleted abroad. This represents a barrier for a sustainable development of the FTS that could be overcome during the project duration developing and transferring a technology for seeding “naked seed”.

- The project designed a “*Methyl Bromide Free Tobacco Protocol*” in order to develop a labeling and certification system. This protocol is currently under discussion with the stakeholders and is expected to be experimentally implemented during 2005.

Regarding the political sustainability of the technical change:

- In 2003, the project promoted the signature of the “Argentine Tobacco Sector Commitment for Protecting the Ozone Layer”, with all the stakeholders.

- The project takes part in the “MB Technical Commission” within the National Secretary of Agriculture (SAGPyA). This Commission is formed by delegates of different departments of the Secretary, INTA, SENASA and province representatives. Projects to prohibit the use of MB in tobacco seedbeds beyond 2007. A ban on the import of MB one pound cans is also on the agenda.

## PRELIMINARY CONCLUSIONS

a) It is possible to achieve important reductions in MB consumption in developing countries in a limited period of time.

b) MB reduction and phase out requires an holistic approach, including obtaining as much as possible political support for the strategy and goals; ensuring that stakeholders participate in designing and implementing the strategies; decentralizing the participation and the design of the technical proposals; and ensuring the availability of an adequate funding.

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# THE IMPORTANCE OF TECHNOLOGY TRANSFER IN THE GLOBAL PHASE OUT OF METHYL BROMIDE

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## ABSTRACT

The transfer of technology and information is accomplished primarily by sharing through education. Training of fumigators occurs at many levels -- company, regional, national and international. The sharing of information in developed and developing countries leads to awareness and implementation of better and alternative methods of fumigation and the eventual phase-out of ozone depleting products like methyl bromide.

**Keywords:** Training, continued education, certification, technology transfer, fumigation, methyl bromide

## INTRODUCTION

*Education, Education, Education* - These are the three most important components in transferring new technologies to offer a sustainable phase-out of methyl bromide (MB). Education comes in different packages. The different methods of transferring these experiences are discussed in this paper along with successful case studies from developed and developing countries.

## START WITH THE INSECT FIRST

The very first step in solving a pest problem is to start with the insect or other pest first. By knowing the habits and needs of a pest, one then can begin to understand what it takes to eliminate them. Classroom biology and pictorial identification is necessary but the way an individual learns about pests is from practical experience in the field watching pests like insects, birds, bats, rodents, feral cats, spiders, and unwanted guests.

<u>An example:</u> Rice weevil, *Sitophilus oryzae* - This is an internal infesting insect that lays its eggs inside the kernel of grains in stored product. The development of the weevil often goes on undetected. This pest can survive the mechanical processing of the grain/rice and ultimately, appear at the end-consumer or export inspection. This pest should be controlled early, in storage, rather than after processing.

## SHARING THROUGH EDUCATION

Sharing through education makes our industry better and helps phase out of ozone depleting substances. Different levels of training that transfer information include:

- Company level
- Regional level
- National Level
- International level

Any time you try to change a standard course of action you will get interference. It is human nature. Change can be difficult for some and easy for others. Farmers are often hard to convince to change and educated people are more open to look at something differently. Education opens eyes to possibilities. Charles Mayo of the Mayo Clinic stated: “The more you know the more you see.” Mr. Orville Redenbacher, an agriculturalist from the US stated: “Those that don’t know will always buy from those that do.” *Sharing Through Education* can also be ‘marketing through education’. The benefit of building strong relationships with your customers and potential customers can offer economic benefits to any business. One person described these educational programs as “getting paid to make a sales call.”

### Training fumigators in developed countries

In 1974 a certification and licensing programme, for all fumigators and people purchasing and using the more hazardous “restricted use” products, required the establishment of a training programme in the US. They were also required to pass a written examination that covered requirements to be a professional applicator. Insurance and fees were required to finish the licensing process. Each state required that to maintain your certification in your particular category, you would need to attend 2-3 continued education training programs in a 3-5 year period.

This licensing program was the conduit for presenting new technology and procedures for the past ten years on alternatives to MB. Each state and each licensed applicator was required to attend and listen to these stories of how to replace this ozone depleting substance. States were eager to allow private companies that work in this specialty field to conduct these continued education courses and felt these private companies were better suited to deliver this message. Private companies also offered training programmes exclusively to their customers that used MB to explain the options available so they could make an intelligent choice.

### Training fumigators in developing countries

There is a need to make training available to all fumigators, importers, and sellers of MB in developing countries. This licensing system has worked for over 30 years in the United States. With the help of the Multi-lateral Fund under the Montreal Protocol this system should be part of every phase-out project. As new technologies and successful techniques are discovered in the rapidly advancing field, training courses should be provided and required for re-licensing. Each fumigator should be required to attend continued education programmes to help voluntarily enforce the sustainable phase out of MB. The Department of Agriculture should be responsible for providing this important service for all fumigators and importers of MB. Each fumigator, importer, and seller of MB should be required to keep good records of all use and transactions to give accountability and traceability to the licensing programme.

## INFORMATION TRANSFER

### Company level

A company should make extension–like services available to customers and non-customers wanting to know more about MB alternatives. This could be by telephone, fax, e-mail, internet website, or company newsletter.

At Fumigation Service & Supply (FSS), Inc. in Westfield, IN USA we have provided these extension-like services. We receive about 400 hits on our webpage each month, we receive frequent phone, fax and e-mail inquiries about MB alternatives. Our newsletter, *Fumigants & Pheromones* is sent to 14,000 people quarterly by post and 2,000 are sent electronically. This newsletter is our best salesman. It is read in 60 countries worldwide and captures the attention of many non-customers that often become new customers. MB alternative articles are found regularly in this eight page publication.

Training is offered to our own company employees on a regular basis in the classroom and also in practical hands on fumigations. Information can be more easily transferred when you reinforce the method by actually doing the work with the trainers. When these fumigators are asked to be the trainers at the next training programme, the transfer of information becomes permanently transferred.

### Regional level

The step from company IT to Regional IT is easy. Success builds on success. Promoting yourself and your company helps widen the transfer of your reputation and your skills to train and teach new methods of fumigating. Guest speakers at continued education meetings can ask for honorariums and expenses for their presentations. At FSS we are asked to speak on over 30 programmes a year. The new contacts made at these regional training meetings only strengthen credibility with the listeners in the audience.

**National level**

National educational programmes are mostly sponsored by trade organizations like the National Pest Management Association, Eurocido, Parasitis, PestEx and Federation of Asia and Oceana Pest Managers Association. T hese programmes attract national and international participants and the transfer of information becomes larger with new ideas coming from diverse people and backgrounds. The promotion of these high budget meetings reaches thousands of people from all over the world. The mention of your name, your company's name and your topic of expertise provides a respect that places you and your company at another level of recognition. Many times the number of people attending your presentation is not that numerous but the people who do attend are typically influential.

**International level**

Since 1993, Insects Limited, Inc. of Westfield, IN has organized and sponsored an international training conference on methyl bromide alternatives in North America and Europe. (Germany 1993, Italy 1995, England 1998, Greece 2001, Denmark 2003, next year in Mexico).

These meetings are attended by fumigators and stored product specialists from over 30 countries. Here companies interested in sharing their results on field trials meet and present. Friendships have been made from these meetings and business relations are developed. These meetings have helped our company of 25 employees to grow in markets that we would likely not be in today. We have become known as experts in stored product protection and methyl bromide alternatives. This international reputation has led to participation with the United Nations and the World Bank.

The implementing organizations (i.e. UNDP, UNEP, UNIDO, GTZ) have contracted our company to do work in developing countries under the Montreal Protocol. As 'fumigation experts' we visit countries like Jamaica, Turkey, Poland, Mauritius, Ivory Coast, Zimbabwe, Thailand, Vietnam, Malaysia, and the Philippines to visit and gather enough information to write a demonstration project or a phase out project for a sector or an entire country. These experiences are tremendously helpful to understand how others in the world live and understand the need to protect the environment. The trainer becomes the student most of the time on these international trips.

## PROSPECTS FOR THE FUTURE

Information transfer is no more than sharing what you know with other people. Shared experiences help us improve and the relationships we build with people can only break down artificial barriers that cause us to resist change. The phase out of MB is a change that needs to be made throughout the world. This global phase-out of MB and other ozone depleting substances will occur when people are willing to share experiences and listen to other's ideas.

# POSTER ABSTRACTS

# AND

# POSTER-PAPERS

The posters displayed at the Conference are summarized as abstracts or poster-papers.

## EVALUATION OF THE EFFECT OF *POCHONIA CHLAMYDOSPORIA* ON *MELOIDOGYNE JAVANICA* AND ITS DAMAGE TO TOMATO GROWN IN PLASTIC HOUSES

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### ABSTRACT

Experiments were conducted over two years in plastic houses, infested by *Meloidogyne javanica*, at two sites in Portugal. The effects were observed of the nematophagous fungus *Pochonia chlamydosporia* isolate Pc-MR, alone or in combination with nematicides, on the nematode and the tomato host. Nematode population densities increased after tomato and decreased during the fallow period. The fungus was able to colonize the tomato roots and was detected in soil and in nematode eggs. Significant differences in yield were found between treatments with and without nematicides.
This research was partially supported by Project nº 244, Programa AGRO, Medida 8-Acção 8.1.

## DAZITOL™ CONTROL OF NEMATODES AND FUNGI ON TOMATO CROPS

**J. SLEVIN**
*On behalf of University of Chile agricultural researchers*

### ABSTRACT

Dazitol™ is a soil fumigant pesticide that kills and controls nematodes, insects, pathogens, and fungi in soil for fruits, vegetables, nuts, and berries. The product is a blend of plant extracts, registered in many countries, bio-degraded into organic matter, and is produced in food-processing plants. Commercial field trial data from researchers at the University of Chile were shown as two posters: 1/ **Effectividad *In Vitro* De Dazitol Sobre Cepas De Pathogenos Del Tomate**. Investigators : Jaime Montealegre, Department of Plant Pathology, University of Chile; Rodrigo Reyes and Miguel Bravo, Agricultural Engineers; and 2/ **Evaluacion del Producto “Dazitol en el Control de Nematodos Fitoparasitos en Tomates Bajo Plastico**; Investigators: Erwin Aballay, University of Chile, Nematologist

## PAN-EUROPEAN GROUNDWATER STEWARDSHIP OF THE SOIL FUMIGANT 1,3-DICHLOROPROPENE AND METABOLITES

**S. KNOWLES**
*Dow AgroSciences*

### ABSTRACT

The fumigant 1,3-dichloropropene is marketed by Dow AgroSciences as Telone™ and with chloropicrin as Telopic™. These soil fumigants are applied by drip irrigation/soil injection in defined high pest infestation areas and have proven to be successful methyl bromide alternatives. Based on intrinsic properties and use rates, assessment of groundwater risk is needed. Actual field measurements from aquifers in high 1,3-D use areas have been made in 4 major countries (Italy, Spain, France, UK). Five use regions were selected per country, with a minimum of 5 operational wells per region. After almost 24 months, >99.5% findings were less than the detection limit of 0.05 ppb.

## INTEGRATED APPROACHES TO PEST MANAGEMENT IN STRAWBERRY PLASTICULTURE PRODUCTION IN SOUTHEASTERN USA: OVERVIEW OF THE METHYL BROMIDE ALTERNATIVES PROGRAMME

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### ABSTRACT

A progressive, multi-state, interdisciplinary team was assembled to evaluate and implement alternatives to MB in strawberry production. Researchers and extension specialists have worked collaboratively to investigate alternative chemical products, application methods, and biologically-based management systems in research station and on-farm trials. Strengths and limitations of chemical and compost-based alternatives were identified. New knowledge was generated on the biology, ecology and management of soil-borne pathogens associated with strawberry roots. Detailed economic analysis tools developed aid in decision-making by growers. On-farm demonstrations, extension publications and pre-plant meetings have kept growers informed of research progress.

## *TRICHODERMA* AND COMPOST FOR ROOT ROT MANAGEMENT IN STRAWBERRY TRANSPLANT AND FIELD PRODUCTION SYSTEMS

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### ABSTRACT

Strawberry root rot management requires the use of clean transplants and disease suppressive field conditions. *Trichoderma* biocontrol strains were evaluated for suppression of root pathogens and promotion of plant vigour during transplant production. Compost was inoculated with *Trichoderma* and compared to compost alone and fumigation with Telone-C35 under field conditions. *Trichoderma* treatments reduced root pathogen incidence and stimulated leaf and root growth of transplants. Application of *Trichoderma* as a compost inoculant resulted in successful establishment and survival of the biocontrol agent in the field, but this treatment provided no beneficial effects. Soil fumigation improved plant growth, yield and root health compared to all other treatments.

## PHYSICAL AND CHEMICAL METHODS OF CONTROLLING FUSARIUM WILT OF CARNATION AS ALTERNATIVES TO METHYL BROMIDE TREATMENTS

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### ABSTRACT

Soil solarization (SS) and soil fumigation (MB and 1,3 D:chloropicrin (DC)) treatments were compared with untreated control in a carnation greenhouse (SW Spain) to control *Fusarium oxysporum* f. sp. *dianthi*, the causal agent of Fusarium wilt (FW). SS, under optimal conditions for 6 weeks, controlled FW and could be a feasible MB alternative. Nevertheless it implies a crop rotation, from September to May following SS, with non-host ornamental crops. Although DC treatment was satisfactory, the permitted application in greenhouses (emulsified formulation applied by the drip irrigation system) has a lower efficacy than MB and is less effective than the shank injection previously tested.

## PRELIMINARY RESULTS ON THE USE OF COMPOSTS FOR THE CONTROL OF FUSARIUM WILT OF CARNATION

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### ABSTRACT

Soil amendments with composts of vegetable (CVR) and cork residues (CCR) reduced the incidence of Fusarium wilt (FW) of carnation in a pot experiment with artificial infestation by *Fusarium oxysporum* f. sp. *dianthi*. The application of these two treatments to artificially infested soil or the hydroponic crop on a CCR substrate, in a plastic house in the production area of NW Cádiz, Spain, were ineffective in reducing FW as compared to untreated control, both in a susceptible and in a resistant carnation cultivar. However, yield was significantly higher in the susceptible cultivar grown in the hydroponic substrate.

## EFFECT OF CHEMICAL ALTERNATIVES TO METHYL BROMIDE ON SOIL-BORNE DISEASES AND SOIL FUNGAL AND NEMATODE COMMUNITIES IN SPANISH STRAWBERRY NURSERIES

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### ABSTRACT

Strawberry runners are a high-value cash crop in Spain that requires vigorous transplants free of pathogens. Pre-plant soil fumigation with methyl bromide (MB), or with mixtures of MB and chloropicrin (PIC), is a standard practice for controlling soil-borne diseases. However, use of MB will be forbidden in European Union countries by the year 2005. For this reason several soil fumigants (PIC, 1,3-dichloropropene, dazomet, metam-sodium, metam potassium, propylene oxide, and dimethyl disulfide) were evaluated in combination with different plastic films as alternatives to MB soil fumigation of strawberry nurseries. Because the known broad activity of these compounds, their effects on strawberry soil fungal communities were also studied. The studies were conducted over a six-year period, with fumigant applications prior to planting. Verticillium wilt (caused by *Verticillium* spp.) and crown rot (caused by *Phytophthora cactorum*) were the main diseases. PIC, 1,3-dichloropropene and dazomet compared well with MB fumigation for control of strawberry nursery diseases. Furthermore, 1,3-dichloropropene and MB, applied at 50% rate under virtually impermeable film provided effective disease control in strawberry nurseries. All the fumigants reduced quantitatively the soil fungal and nematode population, but only MB:PIC, and dazomet caused a clear change in their fungal genera composition.

## EFFECT OF CHEMICAL ALTERNATIVES TO METHYL BROMIDE ON WEED CONTROL IN SPANISH STRAWBERRY NURSERIES

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### ABSTRACT

High-elevation nurseries for strawberry plant production are important in Spain. Weed control is one of the key factors to search methyl bromide (MB) alternatives in this cultivation. Results obtained on 2003 field trials to test the herbicide efficiency of different chemical alternative to MB are presented. Two types of field scale trials were planed: Experiments and Demonstrations. Four commercial nurseries were involved on these trials. The study of weed presence was carried all along the crop season, estimating the number and the fresh weigh of weeds. Results obtained in the experimental trials suggested that some of the chemical alternatives showed a behaviour similar to MB:PIC for weed control. However, results obtained from field demonstrations showed a better herbicide efficiency of MB:PIC in relation to the other chemical alternatives studied.

## ATLANTE: A ROOTSTOCK FOR PEPPER

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### ABSTRACT

Several rootstocks have been obtained for the pepper crop as alternative to methyl bromide which are intermediate resistance to *Phytophthora capsici*, as to the most pathotype of *Meloidogyne arenaria*, *M. incognita* and *M. javanica*. Besides, the rootstocks develop a vigorous root system. Because of all this, it can be involved in a strategy made up for the pepper crop in soils with pathogen population and/or subdued to the tiredness effects brought about the crop reiteration on the same soil. The chosen rootstocks have a positive effect on the plant development, the production and the fruit quality. Atlante is a very good representative for this group of rootstocks.

## 1,3-DICHLOROPROPENE COMBINATIONS AS METHYL BROMIDE ALTERNATIVES

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*Dow AgroSciences*

### ABSTRACT

The fumigant 1,3-dichloropropene (1,3-D) is well-known worldwide as it has been registered in 33 countries and 120 crops for many years. It´s technical properties provide significant benefits not only to the farmer but also to the consumer and the environment. Recent studies have proven that 1,3-D is the basic partner in ready-to-use combinations (with other chemicals or non chemical methods) that can be a successful alternative to methyl bromide. The 1,3-D based alternatives are combinations with a/ chloropicrin (as a ready mixture or co-application) b/ metam sodium (separate applications), c/ solarization ( synergism & broader spectrum) and d/ resistant varieties ( additive effect on nematodes in greenhouse conditions).

## SOIL SOLARISATION: COMPUTER SIMULATION COMPARED WITH LABORATORY DATA UNDER LIGHTS

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### ABSTRACT

The paper describes a computer simulation based on a finite difference solution of the conduction equations. Energy flows through different plastic mulches are analysed in terms of conduction, convection and short and long wave radiation. The simulation is compared with temperatures in a mulched container of soil under Compact Source Iodide lamps for around seven daily cycles. Two mulches were tested, a simple plastic film and a plastic bubble film. The agreement between theory and experiment was good for both. The more complicated mulch did not give very significant benefits. The tested model could now be useful for field simulations.

# EFFECT OF CHEMICAL ALTERNATIVES TO METHYL BROMIDE ON SOIL-BORNE DISEASES AND SOIL FUNGAL AND NEMATODE COMMUNITIES IN SPANISH STRAWBERRY NURSERIES

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## ABSTRACT

Strawberry runners are a high-value cash crop in Spain that requires vigorous transplants free of pathogens. Pre-plant soil fumigation with methyl bromide, or with mixtures of methyl bromide and chloropicrin, is a standard practice for controlling soil-borne diseases. Several soil fumigants were evaluated in combination with different plastic films as alternatives for methyl bromide soil fumigation of strawberry nurseries. Because the known broad activity of these compounds, their effects on strawberry soil fungal communities were also studied. The studies were conducted over a six-year period, with fumigant applications prior to planting. Verticillium wilt (caused by *Verticillium* spp.) and crown rot (caused by *Phytophthora cactorum*) were the main diseases. Chloropicrin, 1,3-dichloropropene+chloropicrin (1,3-D:Pic) and dazomet compared well with methyl bromide fumigation for control of strawberry nursery diseases. Furthermore, 1,3-D:Pic and methyl bromide, applied at 50% rate under virtually impermeable film provided effective disease control in strawberry nurseries. All the fumigants reduced quantitatively the soil fungal and nematode population, but only MB:Pic, and dazomet caused a clear change in their fungal genera composition.

**Keywords**: fumigation, methyl bromide, polyethylene film, soilborne plant pathogens, VIF film

## INTRODUCTION

Strawberry runners (transplants) are produced in nurseries in Castilla-León in north central Spain and are then shipped to the fruit production fields throughout Spain and other countries (especially EU countries) each year where they are transplanted. More than 634 million strawberry runners (80% of which were cv. 'Camarosa') were produced in the 1999-2000 season on an area of about 1,100 ha which is the most important runner production area in the EU. The high-elevation nurseries (800 to 1100 m) are located in sandy, flat areas where plants are grown under continental climatic conditions (hot summers, colder winters, and dry conditions). The cultivation system is annual with planting dates between April and May and digging of fresh commercial runner plants throughout October. Ninety five percent of mother plants for Spanish nurseries come from commercial nurseries in California (USA). Application of methyl bromide (MB) to agricultural soils before planting has been the basis to control nematodes, soilborne pathogens and weeds for many years in strawberry nurseries in Spain (De Cal et al., 2004). All Spanish strawberry growers depend on clean nursery stocks each year because there is a risk that pathogens can be transplanted from nurseries to fruit fields. The objective of this research was to evaluate certain soil fumigants in combination with different plastic films as possible alternatives for MB for controlling soil-borne pathogens and their effect on beneficial and detrimental soil fungal communities in Spanish strawberry nurseries.

## MATERIALS AND METHODS

**Treatments and experimental design**. Experiments were carried out during six years; 1998-2003. Two different experimental fields (size of plots was 5.5 m wide by 72 m long) located in Navalmanzano (Segovia, Spain) (A) and Arévalo (Avila, Spain) (B) were used for the experiments. A randomized complete block design with three replications (three blocks) was used in each field. Treatments were applied on March or April. Fumigants were applied alone or combined with other compounds at several doses under plastic films and different years as shown in Table 1.

Table 1: Treatments applied to strawberry nursery soils prior to planting in 1998-2003

| Treatments | Dose | Plastic film[x] | Application year |
|---|---|---|---|
| 1) 1,3-D:Pic (61:35) | 35 $cm^3$ $m^{-2}$ | PE | 1998-2002 |
| 2) 1,3-D:Pic (61:35) | 17.5 $cm^3$ $m^{-2}$ | VIF | 2001-2002 |
| 3) 1,3-D:Pic | 30 g/$m^2$ | VIF | 2003 |
| 4) 1,3-D:Pic (83:17) | 35 $cm^3$ $m^{-2}$ | PE | 1998 |
| 5) Pic | 40g $m^{-2}$ | PE | 1998-2000 |
| 6) Pic | 30g/$m^2$ | VIF | 2003 |
| 7) Dazomet | 50 g $m^{-2}$ | PE | 1999-2002 |
| 8) Dazomet | 35 g/$m^2$ | VIF | 2003 |
| 9) Metam sodium | 125 $cm^3$ $m^{-2}$ | PE | 2000-2002 |
| 10)Metam sodium:Pic | 40:25g/$m^2$ | VIF | 2003 |
| 11) Metam potassium | 160 $cm^3$ $m^{-2}$ | PE | 2000-2002 |
| 12) DMDS | 80 g $m^{-2}$ | PE | 2002 |
| 13) DMDS | 65 g/$m^2$ | VIF | 2003 |
| 14) DMDS:Pic | | VIF | 2003 |
| 15) Propylene oxide | 30g/$m^2$ | PE | 2003 |
| 16) MB:Pic (30:70) | 20 g $m^{-2}$ | VIF | 2002-2003 |
| 17) MB:Pic (50:50) | 20 g $m^{-2}$ | VIF | 1998-2002 |
| 18) MB:Pic (50:50) | 40 g $m^{-2}$ | PE | 1998-2003 |
| 19) untreated | - | - | 1998-2003 |

[x] PE=polyethylene, VIF=virtually impermeable film.

Transparent, low-density polyethylene (PE) or co-extruded 3-layer virtually impermeable films (VIF) were used after fumigations and left in place for at least 14 days. Hand weeding was used to control weeds.

**Effects on soil fungal population.** Populations of soil fungi (total (PDAs), *Fusarium* spp. (FUS), *Pythium* spp. (PY), *Verticillium* spp. (VER), *Phytophthora* spp. and *Rhizoctonia* spp) were estimated in each plot before and after treatments as colony forming units (CFU) $g^{-1}$ dry soil as described in De Cal et al (2004). Fungi on PDAs were identified to genus in 2001-2003, before and after each treatment. The genus frequency for each treatment and similarity coefficients between soil samples before and after application of treatments were calculated as described in De Cal et al (2004).

**Treatment effects on strawberry diseases.** Mother strawberry plants cv. 'Camarosa' from California nurseries were planted on May and runner plants were harvested on October. Three rows of 115 strawberry plants/row were planted in each plot. Three hundred and sixty additional mother strawberry plants were transferred to humid chambers and the presence or absence of fungal pathogens on the crowns and roots of the plants was determined after 7 to 15 days incubation at 20 to 25ºC. The incidence of crown and root diseases in each plot was recorded three times after transplanting throughout the season. Twenty plants (mother and its runners) in the center row of each plot were arbitrarily sampled on July, August, September or October.

## RESULTS AND DISCUSSION

Soil fungal populations in Spanish strawberry nurseries were clearly reduced in number and composition after pre-plant soil fumigation. A reduction in soil fungal populations isolated in PDAs were observed after application of fumigants except for 2002 in Navalmanzano, and for 1,3-D:Pic (83:17)+PE applied only in 1998 (Table 2). Similar soil fungal reductions were observed with all fumigants, except for DMDS+PE and propylene oxide (Table 2). *Fusarium* populations were reduced by all fumigants in some year, except for DMDS+PE and propylene oxide. The lowest reductions were obtained with 1,3-D:Pic+VIF (17.5 $cm^3$ $m^{-2}$), metam sodium, and metam potassium (Table 2). *Pythium* population was dramatically reduced by all fumigants every year, except propylene oxide. *Verticillium* populations were reduced by fumigants (except in the case of Navalmanzano in 2001 and Vinaderos 2003). The lowest reductions were obtained after application of metam sodium, metam potassium and DMDS+PE (Table 2). MB:Pic, 1,3-D:Pic, Pic alone, dazomet, and metam sodium fumigations had been reported to show a large effect on soil fungi, reducing populations in different soil crops, reaching 100% in some cases (Locascio et al., 1997). In 2002 reduction of soil populations was not observed in Navalmanzano.

This year, a compost was applied to this field between treatment application date and the second soil sampling date that might have enhanced soil microbial populations. Differences in the level of reduction were obtained with some treatments. 1,3-D:Pic (83:17) applied at 35 $cm^3$ $m^{-2}$ did not reduce significantly soil fungal population in 1998, probably due to lower chloropicrin range. Although dazomet and metam sodium are both transformed to the same biocidal product, methyl isothiocyanate (Elliott & Des Jardin, 2001), their effect on strawberry soil fungal populations was significantly different (dazomet reduced more populations than metam sodium), perhaps due to their different application methods in Spanish strawberry nurseries (Elliott & Des Jardin, 2001). Dazomet was incorporated to soil and then covered with PE film while metam sodium was broadcast shank-applied under PE film. Metam sodium applied by shank injection moves short distances from points of injection and its distribution is inadequate for effective pathogen control (Smelt & Leistra, 1974). Soil fungal populations were similarly reduced by MB:Pic (50:50) applied at a dosage of 20 or 40 $cm^3$ $m^{-2}$. In contrast, application of 1,3-D at half dose under VIF film (17.5 $cm^3$ $m^{-2}$) showed a lower reduction in soil fusarium populations.

VIF films are only slightly permeable to fumigant gases, this involves a higher chemical efficacy and reduces application rates of MB:Pic due to a higher pesticide retention within soil. Although VIF films are more expensive than PE, the subsequent fumigant dosage reduction compensates this additional cost). In contrast, few differences were observed on fungal genera isolated before and after treatment The most common genus of fungi isolated in non-fumigated plots was *Penicillium*, followed by *Alternaria*, *Fusarium*, *Morteriella*, and *Cladosporium.* However, in those plots treated with MB or dazomet, frequencies of fungal genera were different before and after treatments (similarity coefficients were < 0.5) and an increase of frequency of *Trichoderma* spp. and *Penicillium* spp and a reduction of frequencies of, *Morteriella* spp., *Fusarium* spp., *Cladosporium* spp. or *Alternaria* spp. was observed. Analysis of mother plants from California showed infections by fungal pathogens such as *Phytophthora cactorum*, *Botrytis cinerea*, *Fusarium* spp., *Pythium* spp., *Verticillium* spp., and *Colletotrichum* spp.

Pre-plant soil fumigation of strawberry nurseries with 1,3-D:Pic, Pic alone or dazomet resulted in significant reduction of disease incidence, similar to that obtained with MB:Pic, while metam sodium and metam potassium only reduced disease incidence for one year. Nevertheless fumigation treatments were correctly applied: all of them reduced populations of soil fungi (Table 2-3). In 2002 and 2003, all treatments, including the untreated control, showed little disease development caused by soilborne pathogens. In 1999 and 2001, infections were mostly caused by *P. cactorum*, and by *Verticillium* sp. in 2000 (Table 3). Although 1,3-D:Pic is registered and available for use as soil fumigants in Spain, there is resistance by regulators in some countries to the use of relatively high rates (Duniway, 2002). However, it is possible to use 1,3-D:Pic at one half the recommended dosage under VIF film to achieve effective disease control in strawberry nurseries. The PE films used commonly for MB fumigation, provide a poor barrier, and enable the escape of fumigant to the atmosphere during the fumigation process, while VIF films retain fumigants in soil for longer periods. VIF films are more expensive than PE, but the subsequent fumigant dosage reduction may compensate for the additional cost.

## CONCLUSIONS

Strawberry production in Spain depends on pre-plant soil fumigation in a sequence of nursery propagation steps. In general, when fumigants are applied to soil at rates necessary to control soil-borne fungi, pathogens elimination and change of other soil components are accepted since there is a partial sterilization of the fumigated zone. Among disposable chemical alternatives to MB:Pic proposed for strawberry disease control in Spanish nurseries dazomet and Pic alone caused the same quantitative and qualitative changes that MB:Pic on fungal soil populations, while a lower effect on soil population was recorded with 1,3-D:Pic+VIF (17.5 $cm^3$ $m^{-2}$), treatment that arose the same disease control as MB:Pic (De Cal et al., 2004).

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Table 2: Significant percentage of reduction of fungal populations isolated on potato dextrose agar plus streptomycin sulphate (PDAs), Fusarium medium (FUS), Pythium medium (PY) and Verticillium medium (VER) during 5 years from strawberry nursery soils after fumigation treatments at Navalmanzano (Segovia, Spain)(A) and Arévalo (Avila, Spain).[*]

| T* | 1998 | | | | | | | | 1999 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PDAs | | FUS | | PY | | VER | | PDAs | | FUS | | PY | | VER | |
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| 1 | - | 99 | 92 | 99 | 99 | 99 | 99 | 99 | 99 | - | - | 94 | 88 | 99 | X | X |
| 2 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 4 | - | - | 99 | 99 | 99 | 99 | 99 | 99 | X | X | X | X | X | X | X | X |
| 5 | - | 96 | 99 | 99 | 99 | 99 | 99 | 99 | 95 | - | - | 96 | 83 | 98 | X | X |
| 6 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 7 | X | X | X | X | X | X | X | X | 89 | 82 | 99 | 81 | 96 | 92 | X | X |
| 8 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 10 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 11 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 12 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 13 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 14 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 15 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 16 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 17 | - | - | 84 | 99 | 99 | 99 | 67 | 99 | 98 | - | - | 95 | 75 | 99 | X | X |
| 18 | 96 | - | 93 | 99 | 99 | 99 | 99 | 87 | 97 | - | - | 79 | 99 | 90 | X | X |

| T* | 2000 | | | | | | | | 2001 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PDAs | | FUS | | PY | | VER | | PDAs | | FUS | | PY | | VER | |
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| 1 | 90 | 72 | 99 | 99 | 99 | 87 | 99 | 79 | 93 | 78 | - | 87 | 99 | 99 | - | X |
| 2 | X | X | X | X | X | X | X | X | 98 | 74 | - | 64 | 99 | 99 | - | X |
| 3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 4 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 5 | 60 | 60 | 99 | 99 | 99 | 82 | 99 | 99 | X | X | X | X | X | X | X | X |
| 6 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 7 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 98 | 99 | 94 | 99 | 99 | 99 | - | X |
| 8 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 9 | 82 | 82 | - | 61 | 92 | 95 | 63 | 62 | 97 | 94 | - | 94 | 77 | 99 | - | X |
| 10 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 11 | 80 | 78 | 99 | 64 | 97 | 86 | 94 | 81 | 93 | 97 | 99 | 99 | 94 | 98 | - | X |
| 12 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 13 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 14 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 15 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 16 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 17 | 79 | 79 | 67 | 99 | 92 | - | 99 | 83 | 98 | 96 | - | 99 | 98 | 99 | - | X |
| 18 | 97 | 97 | 94 | 99 | 82 | 58 | 99 | 99 | 99 | 63 | 95 | 89 | 99 | 99 | - | X |

| T* | 2002 | | | | | | | | 2003 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PDAs | | FUS | | PY | | VER | | PDAs | | FUS | | PY | | VER | |
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| 1 | - | 96 | - | - | X | 90 | 99 | 90 | X | X | X | X | X | X | X | - |
| 2 | - | 96 | - | - | X | 99 | 92 | 99 | X | X | X | X | X | X | X | - |
| 3 | X | X | X | X | X | X | X | X | 99 | 98 | 99 | 98 | 99 | 99 | 99 | - |
| 4 | X | - | X | X | X | X | X | X | X | X | X | X | X | X | X | - |
| 5 | X | - | X | X | X | X | X | X | X | X | X | X | X | X | X | - |
| 6 | X | X | X | X | X | X | X | X | 99 | 98 | 98 | 99 | 98 | 99 | 96 | - |
| 7 | - | 99 | - | 99 | X | 99 | 99 | 99 | X | X | X | X | X | X | X | - |
| 8 | X | X | X | X | X | X | X | X | 99 | 99 | 99 | 99 | 99 | 99 | 99 | - |
| 9 | - | 92 | - | - | X | 95 | 86 | - | X | X | X | X | X | X | X | - |
| 10 | X | X | X | X | X | X | X | X | 99 | 99 | 99 | 99 | 99 | 99 | 99 | - |
| 11 | - | 94 | - | - | X | 96 | 83 | 70 | X | X | X | X | X | X | X | - |
| 12 | - | 58 | - | - | X | 59 | 75 | 63 | X | X | X | X | X | X | X | - |
| 13 | X | X | X | X | X | X | X | X | 99 | 95 | 75 | - | 89 | 96 | 92 | - |
| 14 | X | X | X | X | X | X | X | X | 99 | 97 | 99 | 95 | 99 | 97 | 99 | - |
| 15 | X | X | X | X | X | X | X | X | 95 | 97 | - | - | - | - | - | - |
| 16 | - | 98 | 97 | - | X | 93 | 99 | 99 | 99 | 99 | 99 | 93 | 99 | 94 | 99 | - |
| 17 | - | 97 | 96 | - | X | 99 | 99 | 99 | X | X | X | X | X | X | X | - |
| 18 | - | 95 | 97 | - | X | 99 | 99 | 99 | 99 | 99 | 99 | 98 | 99 | 99 | 99 | - |

[*] Data are the mean of 3 significant replicates. -= non significant reduction. X= no determination.

[+] See Materials and Methods for details of treatments

Table 3: Percentage of strawberry runner plants infected with *Verticillium* sp. (VER), *Phytophthora cactorum* (PC) or other unidentified crown or root rot (O)[x].

| Treatment[y] | 1999 | | | 2000 | | | 2001 | | |
|---|---|---|---|---|---|---|---|---|---|
| | O | VER | PC | O | VER | PC | O | VER | PC |
| 1,3-D:Pic +PE | 0.0 a | 0.0 b | 0.0 b | 1.7 a | 1.7 b | 0.0 b | 1.7 a | 0.0 a | 3.3 b |
| 1,3-D:Pic+VIF | - | - | - | - | - | - | 1.7 a | 0.0 a | 6.7 b |
| Pic+PE | 0.0 a | 0.0 b | 0.0 b | 0.0 a | 0.0 b | 0.0 b | - | - | - |
| Dazomet+PE | 0.0 a | 0.0 b | 0.0 b | 1.7 a | 3.3 b | 3.3 b | 7.0 a | 0.0 a | 8.2 b |
| Metam sodium+PE | - | - | - | 1.7 a | 5.0 b | 0.0 b | 4.4 a | 0.0 a | 24.5 ab |
| Metam potassium+PE | - | - | - | 0.0 a | 1.7 b | 1.7 b | 5.9 a | 1.8 a | 28.1 ab |
| DMDS | - | - | - | - | - | - | - | - | - |
| MB:Pic (30:70)+VIF | - | - | - | - | - | - | - | - | - |
| MB:Pic (50:50)+VIF | 0.0 a | 0.0 b | 0.0 b | 0.0 a | 0.0 b | 0.0 b | 0.0 a | 0.0 a | 3.3 b |
| MB:Pic (50:50)+PE | 0.0 a | 0.0 b | 0.0 b | 0.0 a | 0.0 b | 0.0 b | 1.7 a | 1.7 a | 3.3 b |
| Untreated | 1.7 a | 11.7 a | 3.3 a | 3.3 a | 45.0 a | 13.3 a | 0.0 a | 7.7 a | 40.1 a |
| SME | 1.4 | 18.1 | 1.3 | 7.3 | 25.0 | 6.2 | 27.2 | 11.0 | 165.1 |

[x]Values are means of 3 plots or replicates. Twenty plants (mother + its runners) in the center row of each plot were arbitrarily sampled and examined visually. From these plants those with any disease external symptoms (e.g., collapse, wilting, rot, necrosis, spots) were recorded and taken to the laboratory, where the causal agents were determined. Means followed by the same letter in each column is not significantly different (p>0.05) by the Student-Newman-Keul's test. - = not determined. SME= square mean error from ANOVA

[y] See Table 1 for details of treatments

# EFFICACY OF SULFURYL FLUORIDE (PROFUME™ GAS FUMIGANT) FUMIGATIONS COMPLETED IN A CHAMBER UNDER NORMAL ATMOSPHERIC PRESSURE AND VACUUM FOR THE CONTROL OF STORED PRODUCT INSECTS OF NUTS IN ITALY

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## ABSTRACT

Three experimental chamber fumigations of hazel, almonds and Brazil nuts were undertaken with sulfuryl fluoride (ProFume™ gas fumigant) to determine the efficacy of the fumigant on a range of stored product insects (SPIs) species and life stages. Two normal atmospheric pressure (NAP) fumigations at different temperatures and one under vacuum were completed using a commercial fumigation chamber. Sacks of nuts were stacked into the chamber and four SPIs bioassays were placed at different locations in each of the fumigations. The exposure times ranged for the NAP from 21.8 to 22.3 hours and temperature from 13.3 to 22.5°C; vacuum fumigation exposure time was 4.7 hours and temperature range 22.3 to 27.4°C. Dosage was determined using the ProFume Fumiguide™. Following exposure the chamber was aerated and cleared of sulfuryl fluoride and the bioassays removed and incubated under laboratory conditions and assessed for mortality. Complete mortality was recorded for most of the SPIs following fumigation NAP and vacuum fumigations. The trials confirmed that sulfuryl fluoride is an effective fumigant for the eradication of SPIs from nut commodities.

**Keywords:** Sulfuryl fluoride, ProFume, chamber fumigation, nuts, stored product insects.

## INTRODUCTION

ProFume gas fumigant (99.8% sulfuryl fluoride) has achieved several country registrations for use in the food industry and is undergoing commercialisation in Italy, Switzerland, USA and the UK. Registration submissions have also been made in France, Germany and Canada. Efficacy studies in laboratory chambers have determined the dose responses of sulfuryl fluoride and confirmed its effectiveness on all life stages of a range of SPIs including Mediterranean flour moth (*Ephestia kuehniella*), Indian meal moth (*Plodia interpunctella*), rust-red flour beetle (*Tribolium castaneum*), confused flour beetle (*Tribolium confusum*) and saw-toothed grain beetle (*Oryzaephilus surinamensis*). Dosages have been determined under a range of conditions and have been verified in over 50 field fumigations in emptied flour mills and food processing plants as well as chambers and stacks in Europe and the USA. Efficacy studies are continuing to establish required dosages on many other important insect pests in the food industry.

Commercial scale chamber fumigation trials reported here were undertaken to validate the efficacy of sulfuryl fluoride on a range of SPIs in nuts. Two trials were completed under NAP and one under vacuum. These trials were designed to be as close as possible to current commercial practice for chamber fumigations.

## MATERIALS AND METHODS

### Fumigation site, nut commodities, chamber

The experimental chamber fumigation trials were carried out between the 9 – 12 October 2003 on an Industrial Park at the premises of a fumigation chamber manufacturer Nuovavitervacuum s.r.l., Via S. Maria in Silice, 13, 01100 Viterbo, Italy. The chamber was positioned outside on a concrete base with a roof canopy to protect it from rain and was open to air on all sides. The nuts included in the trials were supplied by the Italian dried fruit and tree nut distributors Noberasco S.p.A., Regione Bagnoli, 5 – 17031 Albenga (SV), Italy and consisted of: shelled hazelnuts from Rome area, in-shell hazelnuts from Naples area, in-shell almonds from Sicily and in-shell Brazil nuts from Brazil. The nuts were packaged in open weave nylon sacks, each sack weighed 50 kg.

The fumigation chamber was constructed of welded steel, rectangular in shape and measured 1.8 m high x 1.65 m wide x 4.0 m long creating a volume of 11.88 $m^3$. The chamber was fitted with heating, cooling and aeration systems. Heating was achieved by air circulation thorough a low temperature electric resistance system and cooling via an air conditioning unit installed inside the chamber. For each NAP fumigation the chamber was filled with sacks of nuts stacked together with polystyrene panels. Each 50 kg sack took up a volume of 0.13 $m^3$. For each fumigation a total of 9 bags of shelled hazel nuts and 6 of mixed nuts were placed in the chamber making a total volume of 1.95 $m^3$. During the loading of the polystyrene piles and the bags of nuts monitoring lines, to measure fumigant concentration, temperature data loggers and insect bioassays were positioned. For the vacuum fumigation polystyrene was not used.

### Efficacy determination

Three SPIs species Indian meal moth (*Plodia interpunctella*), rice moth (*Corcyra cephalonica*) and confused flour beetle (*Tribolium confusum*) were obtained from laboratory cultures from the Institute of Entomology, Milan University. Each species included the presence of different life stages (*P. interpunctella*: eggs, larvae, pupae; *C. cephalonica*: eggs, pupae; *T. confusum*: mixed brood (eggs, larvae, pupae and adults). Adults and mixed brood of tobacco (cigarette) beetle (*Lasioderma serricorne*) were also obtained from laboratory cultures from BTL Bio-Test Labor GmbH Sagerheide, Birkenallee 19, D-18184 Sagerheide, Germany. The bioassays placed in a plastic incubation boxes for transportation to the fumigation site. Untreated controls were kept in the incubation box in an adjacent building to the fumigation chamber at the fumigation site and also at the laboratory. For each of the three fumigations the bioassays were placed within the chamber at four different locations: buried within a bag of shelled hazel nuts in the centre of the stacked bags; between the bags of nuts in the middle of the stacked bags and at the bottom of the stack; outside the bags of nuts at the back of the stacked bags and at the top of the stack; outside the bags of nuts at the front of the stacked bags and at the bottom of the stack. Following exposure the bioassays were returned to each laboratory for mortality assessments.

### Mortality assessment

The returned fumigated and control bioassays were maintained at 27.0 ± 1°C and 70 ± 5% r.h., 12 hours light and 12 hours dark at the Institute of Entomology, University of Milan and mortality assessments were completed after 42 days. Survival was assessed on the basis of emergence of adults or larvae. The efficacy was evaluated according to the Schneider-Orelli (1947) formulae. The *L. serricorne* bioassays were returned to the BHL Laboratory and incubated at 25°C and 70% r.h. Survival of immature stages was assessed on the basis of subsequent emergence of adults after 64 – 66 days after fumigation. Each sample was scored for insects as live (able to walk more or less normally), knocked down (unable to walk but able to move appendages; fall over if placed on feet), dead (no movement or occasional sporadic twitching of appendages).

**Fumigation treatments, monitoring fumigant concentration and temperature**

A commercial cylinder of ProFume was placed on the platform of a programmable scale (Ritchie Yellow Jacket, Digital Electronic Charging Scale, Programmable Version 68811, Ritchie, Engineering Co., Inc, USA) and sulfuryl fluoride introduced in the chamber. The dosage and the amount required was determined using the ProFume Fumiguide (a PC based software program). Two 24 hour fumigations at NAP at different temperatures and one 4 hour vacuum fumigation (700 mm Hg) at ambient temperature were targeted. Polyethylene monitoring lines were placed at bioassay locations for the two NAP fumigations and connected to a model D Fumiscope™ (Key Chemical and Equipment Company, Clearwater, Florida, USA) to measure the concentration of sulfuryl fluoride. It was not possible to measure the concentration during the vacuum fumigation as the pump in the Fumiscope could not draw a sample air/sulfuryl fluoride mix against a vacuum. However a measurement was completed immediately after releasing the vacuum and before aeration. Temperature was monitored throughout each fumigation using Gemini miniature data loggers (Gemini Data Loggers Ltd., Chichester, Sussex, UK) placed at the same bioassay locations for both the NAP and vacuum fumigations.

The chamber vacuum pump was used to remove the fumigant following the exposure period. After 2 to 3 changes of air (air washings) were completed the fumigator, wearing positive pressure self containing breathing apparatus, opened the chamber doors and measured the concentration of sulfuryl fluoride with an Interscan™ Gas Analyser Model GF 1900 (Interscan Corporation, Chatsworth, California, USA). When the concentration reached 3 ppm the chamber was declared cleared and unloaded.

## RESULTS AND DISCUSSION

For both the NAP fumigations the concentration equilibrium was achieved rapidly *c.* one hour after initial gas introduction. These results demonstrated the effective penetration of the fumigant throughout the stacked nuts. Similar concentrations recording were subsequently made throughout the exposure period and during the aeration phase. NAP fumigation at the low temperature range of 13.5 – 18.8$^{o}$C achieved 100% mortality of all SPIs species and life stages with the exception of *L. serricorne* in one location (buried within a bag of shelled hazel nuts in the centre of the stacked bags). At this location 99% mortality was recorded. NAP fumigations at the higher temperature range of 22.3 – 27.4$^{o}$C resulted in 100% mortality of all SPIs and life stages including *L. serricorne.* These results confirm that improvements in efficacy of sulfuryl fluoride can be made by increasing the temperature. The sulfuryl fluoride vacuum fumigation at the temperature range of 19.1 – 19.7$^{o}$C also achieved complete mortality of most of the SPIs and life stages. A very low survivorship was recorded for *C. cephalonica* and *T. confusum* larvae. The chamber fumigations under commercial conditions of NAP and vacuum confirmed that sulfuryl fluoride is an effective fumigant for the eradication of SPIs from shelled and unshelled nut commodities. Further work is being undertaken to evaluate the effectiveness of vacuum fumigation on SPIs including dried fruit beetle (*Carpophilus hemipterus*).

## ACKNOWLEGMENTS

We would like to thank Aldo Gelli, Colkim S.r.l., Via Piemonte, 50 – 40064 Ozzano Emilia, (BO) and Liberato Vitillo, Vitillo Liberato S.r.l., Piazza de Santis, 9 – 83031 Ariano Irpino (AV) for technical assistance in planning and implementing the fumigations.

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## HEAT TREATMENT FOR DISINFESTATION OF NITIDULID BEETLES FROM DATES

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## ABSTRACT

Nitidulid beetles infest dates during and after harvest. Fumigation with methyl bromide (MB) upon arrival at the packing plant causes a high proportion of larvae and adults to emigrate from the fruit before they succumb and also effectively controls infestation. *Laboratory experiments* were carried out to test the effectiveness of heat treatment as an alternative to MB, which would remove insects from the dates, prevent insect development and preserve fruit quality. Test insects were *Carpophilus hemipterus* larvae reared on a synthetic food medium and held at 26°C and 75% relative humidity. Artificial feeding sites destined to simulate the dates were prepared consisting of cardboard rectangles placed on food medium contained in Petri dishes. Exposure times of 2 hours after the feeding sites reached the target temperature were employed. Temperatures of 40°, 45°, 50° and 55°C were tested. Disinfestation was greatest (92.3%) at 50°C. At 50° and 55°C 100% mortality was obtained. *Field trials* were carried out at a date drying facility. Crates with artificially infested dates were positioned at strategic sites and the drying pass of 45ºC was preceded by a 2 hour pass at a target temperature of 50ºC. Results showed high disinfestation and complete mortality.

**Key words:** Dried fruit, dates, disinfestation, Nitidulid beetles, *Carpophilus* spp., heat treatment, methyl bromide alternatives, IPM, storage pest control.

## INTRODUCTION

Dried fruit insects cause serious damage to the fruit rendering it unfit for human consumption and also contaminate it, rendering it unacceptable for marketing in international trade. Several stored-product insects commonly infesting dried fruit, particularly moths of the family Phycitidae and beetles of the family Nitidulidae, are also field pests. The initial source of infestation is frequently on ripening fruit on the tree, with infestation continuing in the packing-houses and during storage. Consequently it is an accepted practice both in the date and fig industries, as well as with other fruits and nuts, to fumigate the harvested fruit immediately upon arrival at the packing-houses, in order to break the chain of insect infestation. Fumigation using methyl bromide (MB) in fumigation chambers is the accepted practice. MB causes the adults and larvae to abandon the fruit before they die (Donahaye et al. 1991; Navarro et al. 1989). This decontamination effect is invaluable in actually decreasing the infestation levels of dead insects remaining in the fruit.

The objective of this work was to study the effectiveness of heat treatment as an alternative to methyl bromide (MB), to remove insects from the dates and prevent insect development and preserve fruit quality at the laboratory. In addition, field trials were carried out to demonstrate the feasibility of the method in a commercial scale date drying installation using an electrically assisted solar energy system expressly designed for this purpose.

## MATERIALS AND METHODS

### Laboratory studies

Laboratory cultures of the test insect *Carpophilus hemipterus* originated from infested dates. They were reared under standard conditions of 26ºC and 75% relative humidity on an artificial diet. Larvae used in the experiments were 6-8 days old. The experiments to determine percent disinfestations and mortality levels of the *C. hemipterus* larvae were carried out at four temperatures of 45º, 50º, 55º and 55ºC.

Artificial feeding sites were prepared to simulate the dates. They consisted of cardboard rectangles placed on food medium contained in Petri dishes. Larvae were placed in the Petri dishes, and penetrated beneath the cardboard rectangles. After 24 hours, while the larvae inside, the feeding sites were placed in the exposure chambers. Exposure was carried out in 2.54 L desiccators. Temperatures within the artificial feeding sites were always 1° to 2°C lower than the nominal test temperature in the desiccators and it took approximately 60 min to reach to the test temperature from 26°. For each treatment, an exposure time of 2 hours, after the feeding sites reached the test temperature, were employed. The ratio of the number of insects found outside the feeding sites to the total number of insects was used to describe the term "percent disinfestation". After each treatment the number of survivors was examined and percentage of mortality calculated.

**Field trials**

Field trials were carried out in the commercial drying facilities of the Timura Company located at the agricultural cooperative Moshav Mehola in the north of the Jordan Valley. The drier takes advantage of solar heat supplemented by an LPG (liquid petroleum gas) heater, used to compensate for temperature drop at the cooler times of the day. Tests were carried out on dates of the Madjoul variety. Crates containing infested dates were exposed in strategic locations of the drier to verify if the heated air caused emigration of larvae as occurred in the laboratory. Below each crate a second empty crate containing a liner was spread to collect the larvae that emigrated from the dates. After treatment the infested dates were analyzed for survival in the laboratory. In each bioassay about 500 larvae per crate were used to test for emigration and mortality. Three subsequent trials were carried out. In each trial four crates were placed in strategic points; two crates on top and two crates at the lower extreme sections. Reported results are average of these three trials.

## RESULTS

**Laboratory studies**

The disinfestation value was greatest at exposure to 50°C (92.3%) this level being highly significantly different from disinfestations at 40° and 55°C (Figure 1). The highest mortality reached 100% and was obtained at 50° and 55°C (Figure 2).

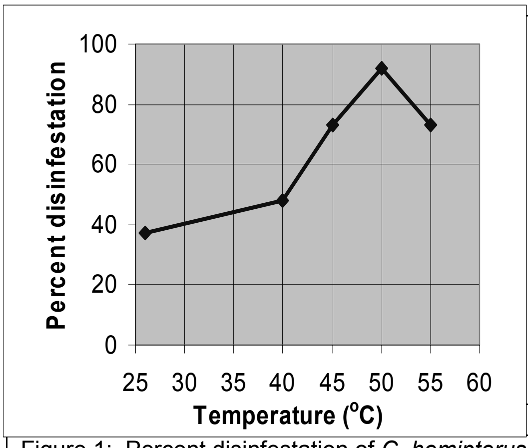


Figure 1: Percent disinfestation of *C. hemipterus* larvae from artificial feeding sites at various temperatures for 2 hours of exposure after the test temperature was reached.

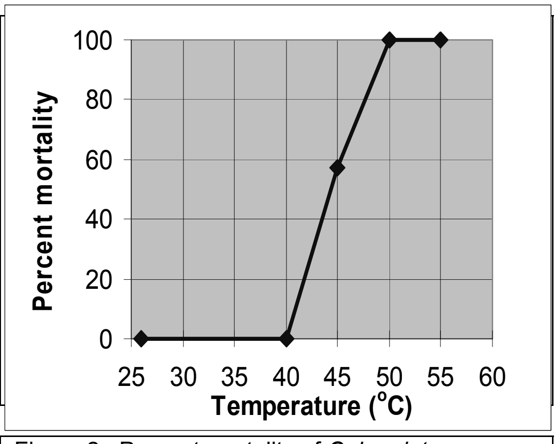


Figure 2: Percent mortality of *C. hemipterus* larvae exposed to various temperatures for 2 hours after the test temperature was reached

**Field trials**

The drying facility consisted of a hot-house (Fig. 3) that accommodated rows of pallets covered by a plastic liner to convey the heated air through the boxes containing dates (Fig. 4). The drier thermostat was set to 50°C and laboratory-infested dates were used as bioassay.
The data indicate that the target temperature of 50°C could be achieved within one hour after the introduction of the dates into the drier. An additional two hours were necessary to achieve emigration and mortality of the insects. Of the dates used for bioassay that were placed at strategic locations near the lower periphery of the drying duct (where air circulation was suspected to be restricted), a temperature drop of between 2° and 3°C was found from the target temperature. These slight differences allowed larval survival at the end of two hours exposure, but mortality was complete when the exposure time was extended to four hours. In the top layers of the drying rows, the bioassays of infested dates revealed total emigration and mortality of larvae at the end of two hours exposure.

## DISCUSSION

Post-harvest quarantine treatments using high temperatures have been studied on various commodities, but the present study is the first on dates to determine the emigration of nitidulid beetles. In our laboratory study a heating time of about 60 minutes was necessary until the temperature reached its target level. This heating time may also affect the emigration rate of the larvae. Previous data that reported on disinfestation levels using MB indicated that the highest disinfestation did not exceeded 90% (Donahaye et al. 1991; 1992). Their disinfestation levels are comparable with those recorded in Table 7 (92.3%).
The heat treatment is intended to replace the conventional fumigation with MB, within the framework of studies to find MB alternatives. Since dates are first disinfested using MB and then dried when necessary, it is expected that this treatment will be most suitable for dates that are subject to drying before storage. As for dates that are already at their moisture content suitable for storage (such as the Deglet-Nur variety), exposure to heat will last no more than two hours after the dates reach the target temperature. Preliminary experiments have shown that at a short exposure of two hours, an insignificant moisture reduction of dates is incurred.

## CONCLUSIONS

Disinfestation from dates in the laboratory was greatest at 50°C and reached 92.3%. Complete mortality was obtained at 50° and 55°C. Since conventional drying temperatures for most date varieties are in the range of 45° to 55°C, application of heat appears an encouraging solution for the treatment of dates as a replacement to MB. This approach was tested at a commercial scale date drying facility and was shown to be feasible with no modification needed to the actual installation. Since at present, dates are first disinfested using MB and then dried when necessary, it is expected that this treatment will be most suitable for dates that are subject to drying before storage.

Figure 3: General view of the drier consisting of a green house.

Figure 4: Individual rows containing ten pallets each located inside the drier

## ACKNOWLEDGEMENTS

This research was partially funded by a grant from the United States-Israel Science and Technology Foundation (USISTF), ARO Project No. 421-0064-03. We thank Eng. Dov Avni, Food Engineer of Mial Impex Company, Mr. Avraam Kopolevitz, Timura Manager and Mial Impex Company for their cooperation during the trials. Dr. Shlomo Navarro thanks Prof. Dr. Ramon Albajes of the University of Lleida, Dr. Rosa Gabarra and Dr. Jordi Riudavets of the Department of Plant Protection of IRTA, Centre de Cabrils, Barcelona, Spain, for inviting him for a sabbatical year and the Ministry of Education, Culture and Sport of Spain for providing the support (reference number SAB2002-0016) that enabled the collaboration during the preparation of this presentation.

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# CONSTRAINTS AND REMEDIES IN THE ADOPTION OF NON-CHEMICAL METHYL BROMIDE ALTERNATIVES FOR VEGETABLE PRODUCTION IN LEBANON

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## INTRODUCTION

The UNDP-Methyl Bromide Alternatives Project for the phase out of methyl bromide in Lebanon in the sectors of vegetables, cut flowers and tobacco was launched by the Ministry of Environment of Lebanon in year 2002, having as objective to phase out 310.2 M tons (186 ODP tons) of methyl bromide, of which, 257.8 metric tons in the vegetables sector (573 hectares), 28.4 tons in the cut flowers sector (63 hectares), and 24 tons in the tobacco sector. This project will achieve complete phase out of methyl bromide in Lebanon by year 2007, in concert with a second project, being implemented by the Ministry of Environment of Lebanon in coordination with UNIDO, that targets the phase out of 84 metric tones of methyl bromide consumed in the strawberry sector. During its first two years (2002 to 2003) the UNDP project has successfully achieved phase out of 28.5 and 36 ODP tons, mainly through the application of non-chemical alternatives such as soil solarization, biofumigation and grafting, making use of a single chemical alternative (1-3, Dichloropropene) in relatively rare instances. Currently, an additional quantity of 54 ODP tons are being phased out with the use of the same alternatives. One of the major successes of the project is the creation of environmental awareness among the growers and consciousness of reward from the technology on the alternatives suggested by the project.

Over the past two years there has been progressive increase in the percentage of growers who have preferred adopting non-chemical alternatives (96.5%) as compared to the growers who prefer chemical alternatives (3.5%). Out of the 2,049 farmers trained on the different alternative techniques, 1,689 farmers selected soil solarization (80.0%), 111 selected biofumigation (5.0%), and 180 for grafted plants (11.4%) while only 69 farmers applied the chemical 1-3, Dichloropropene (3.5%). As a result of the enthusiasm among the growers and the constant encouragement of the Ministry of Environment, the project eliminated 65.72 ODP tons of MeBr in years 2002 and 2003, thus exceeding its initial target of 61.8 ODP tons. Various advantages in the non chemical alternatives over the conventional MBr application make the farmers to select these technologies and fit into their vegetable cropping systems. Among all, the most important aspects include efficiency of the technology in controlling the target pests, low application cost, high yields, and environment friendliness to mention a few. Additionally, uniform plant growth resulting from soil solarization and biofumigation is an encouraging factor.

All these factors have encouraged Lebanese farmers to take personal initiatives and apply the non chemical alternatives suggested by the project on even larger scales than those initially committed to. However, while adopting the alternative technologies in vegetable production, the project faced some constraints in the implementation process. One of the major constraints is the environmental hazard caused by traditional methods of disposal (like dumping away, burying or burning) of polyethylene sheets used in soil fumigation either with methyl bromide or a variety of its chemical and non-chemical alternatives. In addition to an estimate yearly consumption of 2,000 tons of PE in Lebanon, the Methyl Bromide Alternatives Project alone provides around 70 tons of transparent 50 microns thermal polyethylene to the farmers every year. In order to resolve this problem, a PE recycling plant having a capacity of recycling 5 tons of used PE per day has been established in an extensively agricultural area, and provided with the necessary technical information for adding a new parallel line to the factory. Series of farmers training sessions were organised in different regions of the country and through this training program, farmers were encouraged to return the used PE to the recycling plant and a compensation plan was elaborated to reimburse farmers. The Project recollected 20 tons of used PE initially distributed to the farmers by the project and used for soil solarization and the farmers providing used PE will be compensated by the plant at a certain rate/ton. This initiative created a new opportunity for the industrial sector. Current project not only provide the assistance to Lebanon but also to the neighboring countries. In this respect, the project has recently received the visit of a delegation of Jordanian farmers and owners of plant nurseries, and introduced them the grafting technique of vegetable plants through site visits and demo tours.

This experience encouraged the project management to tackle another environmental issue, caused by the burning of plant residues at the end of each season. To overcome this problem the project purchased 2 chopper-shredder machines and made them available to the farmers of all regions. Training sessions were organized to get farmers acquainted with the benefits of using natural compost as soil amendment. Farmers have been trained on using the choppers, in addition to the composting steps and techniques. In a matter of few months, several tons of tomato and cucumber plant residues have been composted and added to the soil. This initiative also helped farmers avoiding the purchase of preparatory organic fertilizers, thus reducing production costs by 5-7%. In conclusion, the Lebanese project is not only exceeding its yearly phase out targets, but it is being able to replace methyl bromide with 100% environment friendly non-chemical alternatives in more than 96% of the cases, with only minimal use of 1-3, Dichloropropene, the single chemical alternative applied by the project.

**UNDP-METHYL BROMIDE ALTERNATIVES PROJECT**

The  for the phase out of methyl bromide in Lebanon in the sectors of vegetables, cut flowers and tobacco was launched by the Ministry of Environment of Lebanon in year 2002, having as objective to phase out 186 ODP tons of methyl bromide, of which, 154.6 ODP tons in the vegetables sector (573 hectares), 17 ODP tons in the cut flowers sector (63 hectares), and 14.4 ODP tons in the tobacco sector.

This project will achieve complete phase out of methyl bromide in Lebanon by year 2007, in concert with a second project, being implemented by the Ministry of Environment of Lebanon in coordination with UNIDO that targets the phase out of 50.4 ODP tons of methyl bromide consumed in the strawberry sector.

During its first two years (2002 to 2003) the UNDP project has successfully achieved phase out of 28.5 and 36 ODP tons, mainly through the application of non-chemical alternatives such as soil solarization, biofumigation and grafting, making use of a single chemical alternative (1-3, Dichloropropene) in relatively rare instances.

Currently, an additional quantity of 54 ODP tons are being phased out using the same alternatives.

One of the major successes is the creation of environmental awareness among the growers and consciousness of reward from the technology on the alternatives suggested by the project.

Table 1: Summary of the quantities of MeBr phased out during the past three years.

| Year | Area requested (dunums) | Area phased out (dunums) | # of farmers trained | Phase out quantity requested (ODP T) | Phase out quantity achieved (ODP T) |
|---|---|---|---|---|---|
| 2002 | 956.00 | 965.00 | 1,023.00 | 25.80 | 26.08 |
| 2003 | 1,334.00 | 1,473.00 | 2,049.00 | 36.00 | 39.68 |
| 2004 | 2,001.00 | 2,260.00 | 3,111.00 | 54.00 | 60.99 |
| **Total** | **4,291.00** | **4,698.00** | **6,183.00** | **115.80** | **126.75** |

## PROGRESS ACHIEVED

Over the past two years (2003 – 2003) there has been progressive increase in the percentage of growers who have preferred adopting non-chemical alternatives (96.5%) as compared to the growers who prefer chemical alternatives (3.5%). In year 2003, out of the 2,049 farmers trained on the different alternative techniques, 1,689 farmers selected soil solarization (80.0%), 111 selected biofumigation (5.0%), and 180 for grafted plants (11.4%) while only 69 farmers applied the chemical 1-3, Dichloropropene (3.5%). As a result of the enthusiasm among the growers and the constant encouragement of the Ministry of Environment, the project eliminated 65.72 ODP tons of MeBr in years 2002 and 2003, thus exceeding its initial target of 61.8 ODP tons. There are several factors, which make the farmers to select the viable alternative technologies and fit into their cropping systems. These include efficiency of the technology in controlling the target pests, low application cost, high yields, and environment friendliness to mention a few. Additionally, uniform plant growth resulting from soil solarization and biofumigation is an encouraging factor.

Table 2: Distribution of alternative areas and sites in year 2003

| Alternative / Region | Solarization | | Biofumigation | | Grafting | | 1-3, D | | Total area (Dunums) | Total # of Sites |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dunums | Sites | Dunums | Sites | Dunums | Sites | Dunums | Sites | | |
| North Lebanon | 247 | 159 | 29 | 12 | - | - | - | - | 276 | 171 |
| Kesrwan & N.M.L. | 214 | 70 | 13 | 6 | 45.5 | 14 | 18 | 4 | 290.5 | 94 |
| Jbeil | 178 | 76 | 21 | 10 | 119 | 42 | 6 | 2 | 324 | 130 |
| S. Mount Leb. | 262 | 135 | 5 | 5 | 4 | 4 | 23 | 15 | 294 | 159 |
| South Lebanon | 279 | 123 | 5 | 4 | - | - | 4 | 2 | 288 | 129 |
| Total | 1180 | 563 | 73 | 37 | 168.5 | 60 | 51 | 23 | 1472.5 | 683 |
| Percentage in terms of area | (80.14%) | | (4.96%) | | (11.44%) | | (3.46%) | | | |

All these factors have encouraged Lebanese farmers to take personal initiatives and apply the non chemical alternatives suggested by the project on even larger scales than those initially committed to.

Results of the alternatives applied

Un-uniform growth of cucumbers following MeBr treatment

Uniform and healthy cucumber plants after soil solarization

while adopting the alternative technologies in vegetable production, the project faced only some minor constraints in the implementation process.

**Additional achievements**

One of the major constraints is the environmental hazard caused by traditional methods of disposal (like dumping away, burying or burning) of polyethylene sheets used in soil fumigation either with methyl bromide or a variety of its chemical and non-chemical alternatives. In order to resolve this problem, a PE recycling plant having a capacity of recycling 5 tons of used PE/day has been established in an extensively agricultural area, and provided with the necessary technical information for adding a new parallel line to the factory.

Through an extensive training program, farmers were encouraged to return the used PE to the recycling plant and a compensation plan was elaborated to reimburse farmers. This initiative created a new opportunity for the industrial sector. The Ministry of Environment and the municipalities were contented.

This experience encouraged the project management to tackle another environmental issue, caused by the burning of plant residues at the end of each season. To overcome this problem the project purchased 2 chopper-shredder machines and made them available to the farmers of all regions. Training sessions were organized to get farmers acquainted with the benefits of using natural compost as soil amendment. Farmers have been trained on using the choppers, in addition to the composting steps and techniques. In a matter of few months, several tons of tomato and cucumber plant residues have been composted and added to the soil. This initiative also helped farmers avoiding the purchase of preparatory organic fertilizers, thus reducing production costs by 5-7%.

## CONCLUSIONS

The Lebanese project is not only exceeding its yearly phase out targets, but it is being able to replace methyl bromide with 100% environment friendly non-chemical alternatives in more than 96% of the cases, with only minimal use of 1-3, Dichloropropene, the single chemical alternative applied by the project.

# EFFICACY OF AGRI-TERRA™ AGAINST PHYTOPARASITIC NEMATODE SPECIES INDIGENOUS TO LOUISIANA

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## ABSTRACT

Agri-Terra™ has proven to be a safe and efficacious material for the management of many economically important phytonematode species in Louisiana. Popular cultivars of all major row crops plus a wide variety of vegetable species were evaluated in microplot and field trials during the period 2000-2003. In every trial, significant reductions in nematode populations were observed following application of this material. Harvest data from microplot trials, averaged over years, showed increases in plant dry weights over those of controls which averaged 51% for cotton, 114% sugarcane, 79% for rice, and 129% for soybean. In field trials, significant yield responses were observed in four consecutive years with cotton and in two of three years with soybean. In a multi-year field trial with sugarcane, the pounds of sugar per ton of cane harvested from the plant crop was numerically, but not significantly, greater than that of the non-treated control. At harvest of the first ratoon crop, however, there was a significant increase in the sugar content per ton of sugarcane.

**Keywords:** Agricultural crops, Agri-Terra™, methyl bromide, nematicide, *Rotylenchulus reniformis,* Telone.

## INTRODUCTION

The reniform nematode, *Rotylenchulus reniformis* (Rr), is worldwide in distribution, has life stages adapted to resist environmental stresses, possesses great fecundity, parasitizes over 50 agriculturally important plant species, has a wide host range and is highly pathogenic to cotton and soybean in the southern United States (Linford & Oliveira, 1940; Robinson et al., 1997; Overstreet & McGawley, 1994, 1998). Since little if any commercial resistance is available, producers are forced to rely on nematicides for management of this devastating pathogen. Traditionally, the most efficacious, reliable, and economically justified materials used have been fumigants since they control other soil borne pathogens in addition to nematodes. While fumigants like Methyl Bromide and Telone are known to be effective against a wide variety of nematodes, concerns about the environmental consequences of their usage have resulted in national and international legislation (Ozone Secretariat 2000) designed to curtail or eliminate their usage in the near future. Since 2000, we have been evaluating the efficacy of a product, Agri-Terra™, produced by Cal Agri Products, LLC of Los Angeles, CA. This material, the active ingredient of which is 1% monobasic potassium phosphate, has proven in laboratory, greenhouse, microplot, and field trials to have nematicidal activity, especially against reniform nematode, equal to or better than either methyl bromide or Telone™. Abstracts of this research have been published previously (McGawley *et al.* 2001; McGawley & Pontif, 2002).

## MATERIALS AND METHODS

### General

Fumigant treatments in both microplot and field trials were applied two weeks prior to planting at a rate equivalent to 75.6L/ha (8 GPA) and Agri-Terra™ was applied as a 1% solution at planting at a rate equivalent to 94.5L/ha (10 GPA). The duration of all trials was full-season and data were collected at harvest. Data was analyzed using the “fit Y by X” Module of JMP (Version 3.3, The SAS Institute, Cary, NC) to test for main treatment effects. Unless otherwise stated, all differences noted were significant at the 5% level.

**Microplot environment**

Microplots are clay pots having top diameters of either 30.5 or 40.6 cm. with soil capacities of 15 and 35 kg., respectively. The 40.6 cm. microplots were used exclusively for sugarcane trials. Fifty-four microplots are set into rim-deep depressions in the soil and spaced 1 meter apart in a 6-by-9 pattern in each of seven outdoor areas. Each microplot area, equipped with overhead fans and an automated irrigation system, is bounded by a 14-meter-long by 9-meter-wide aluminum quonset hut frame open at both ends and covered with clear, 6-mil polyethylene greenhouse film. These coverings are necessary to protect plants in microplots from excessive summer rainfalls common in southern Louisiana. Crops employed in trials include 'Stoneville LA887' cotton, 'Pioneer 9594' soybean, 'Cypress' rice, 'LCP384' sugarcane, 'All Season' cabbage, 'Full Heart' endive, 'Salad Bowl' lettuce and 'Florida Broadleaf' mustard green. In 2000, soil used in microplots was steam-sterilized prior to infestation with nematodes extracted from axenic greenhouse cultures and application of compounds under investigation. For each nematode species, infestation levels used were those most common in Louisiana prior to planting. In 2001-2003, soil used in microplots was collected from field sites in which the crop to be tested had been grown for at least five years and which supported a resident soil microflora and fauna (both pathogenic and non-pathogenic nematodes, fungi, bacteria, soil insects and weed seed) representative of the crop as a whole. Soil collected from these field locations was transported to the microplot sites, sieved to remove large clods, and placed into microplots. Appropriate controls were included in every trial. For 2000, "nematode only," "chemical only," and "no nematode/no chemical" controls were used respectively to confirm a pathogenic nematode population, to evaluate phytotoxicity, and to provide the complete control treatment necessary for statistical analysis. In 2001-2003 "non-treated field soil" and "steamed field soil" controls were employed. On the day of harvest, 500g soil samples were collected from each microplot immediately after removing tops and placing them into paper bags for drying at 43C for 96 hours. Root balls were then removed from microplots, washed free of soil, inspected for damage and photographed where appropriate, and placed into paper bags for drying along with plant tops. Soil samples were transported to the nematology lab where nematodes were extracted using a common centrifugal/sugar flotation technique (Jenkins, 1964), enumerated, and sorted according to genus and species.

**Field environment**

Field trials were conducted at three Louisiana Research Center locations: the St. Gabriel Sugarcane Research Station, the Ben Hur Research Plantation and the Burden Research Center, all in the Baton Rouge vicinity. Plots at each of these locations consisted of four rows with treatments applied to and data collected from the center two rows. All production practices employed, such as land preparation, tillage, fertilization and pesticide usage, were those typical for the crop in Louisiana. Plots were arranged in a randomized block design with five to six replications of each treatment. Individual plots were 26.2 m. long by 1.8 m. on center at St. Gabriel, 27.7 m. long by 1 m. on center at Burden and 18.5 m. long by 1 m. on center at Ben Hur. Fumigants (Methyl Bromide and Telone II each at 8 GPA or 115.2 and 80.8 lbs/A, respectively) were applied two weeks before planting. Immediately following application of fumigants, furrows were closed and sealed using tractor-mounted hipping and row-forming implements. Agri-Terra™ was applied with a hand sprayer to the center of a V-shaped furrow (18 cm. in diameter at its widest point) that was made in the center of each row at the time of planting. Soybean plots were harvested with a single-row, small-plot combine, cotton plots were hand-harvested and sugarcane plots were harvested using a commercial harvester. Soil samples were collected from the center two rows of each plot at mid-season and at harvest using a zig-zag sampling protocol (typically 25 soil cores/plot, each 15.2 cm. deep by 2.5 cm. in diameter) and nematodes were extracted and enumerated in the nematology lab as described above.

## RESULTS

The density of nematode communities, which included root-knot, spiral, ring, stunt and trace amounts of lesion nematodes, were reduced significantly by Agri-Terra™ on all four vegetable species included in the 2000 trial (Table 1.). Using half-rate applications at two intervals rather than a full-rate, at planting application was not beneficial, and in the case of endive, actually resulted in increased numbers of nematodes. Only with mustard green did the control of nematodes result in an increase in plant weight at harvest. In multi-year microplot studies with non-vegetable crops (Table 2.), all Agri-Terra™ treatments resulted in reductions in nematode communities and corresponding increases in plant growth. Differences in dry weights between Agri-Terra™ treatments and those of controls were significant at the 1% level for rice, soybean and cotton. In field trials (Table 3.) Agri-Terra™ was as effective as either Telone II or Methyl Bromide in reducing reniform nematode population levels at harvest on soybean; with cotton, Agri-Terra™ was superior to either of these two materials. On both crops, reniform populations at harvest were only slightly higher than those present prior to planting. Averaged over 4 years, yield of soybeans was increased by 38% and yield of cotton was doubled (Table 4.). At harvest of the first year plant cane portion of the sugarcane cropping cycle (Table 5.) there was a numerical, but non-significant, increase the pounds of sugar per ton of cane harvested. At harvest in year two, the first ratoon crop, application of Agri-Terra™ resulted in a significant increase in sugar yield per ton. Nematode populations associated with this trial (data not shown) were reduced significantly at each of two sampling intervals during each year.

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Table 1 Effect of Agri-Terra™ on Nematode Populations and Weights of Selected Vegetable Species at Harvest in Microplots (Fall, 2000).[1]

| Nematacide Treatment | NEMATODES PER 500G ($10^3$) | | | | DRY PLANT WEIGHT G | | | |
|---|---|---|---|---|---|---|---|---|
| | Cabbage | Endive | Lettuce | Mustard Green | Cabbage | Endive | Lettuce | Mustard Green |
| Agri-Terra™ Once[2] | 333.5b | 18.2c | 214.0b | 10.2b | 270.9a | 188.0b | 101.8b | 490.8a |
| Agri-Terra™ Twice[3] | 286.1b | 73.7b | 237.2b | 7.5b | 302.2a | 190.1b | 87.8b | 471.6ab |
| Control 1[4] | 410.4a | 184.0a | 551.8a | 77.9a | 356.4a | 183.0b | 154.0a | 434.1b |
| Control 2 | 0 | 0 | 0 | 0 | 365.2a | 203.3b | 100.6b | 392.9b |
| Control 3 | 0 | 0 | 0 | 0 | 340.8a | 250.4a | 114.3b | 395.2b |

[1] Values within columns followed by the same letter were not significantly different
[2] 120 ml. applied at planting; [3] 60 ml. applied at planting and 60 ml. applied at midseason.
[4] Controls 1-3 were: Nematodes without Agri-Terra™, Agri-Terra™ without nematodes, and no Agri-Terra™, no nematodes, respectively.

Table 2. Effect of Agri-Terra™ on Nematode Populations and Weights of Selected Crop Species at Harvest in Microplots.[1]

| Nematicide Treatment | NEMATODES PER MICROPLOT ($10^3$) | | | | DRY PLANT WEIGHT G | | | |
|---|---|---|---|---|---|---|---|---|
| | **Rice** | **Sugarcane** | **Soybean** | **Cotton** | **Rice** | **Sugarcane** | **Soybean** | **Cotton** |
| Agri-Terra™ | 18.3b | 124.5b | 44.3b | 49.7b | 96.4b | 473.8b | 191.8a | 104.5a |
| Control 1[2] | 287.5a | 1,339.7a | 438.9a | 463.9a | 53.8c | 221.2c | 83.7b | 69.4b |
| Control 2 | 0 | 0 | 0 | 0 | 183.9a | 1,010.7a | 167.4a | 97.7a |

[1] Values within columns followed by the same letter were not significantly different. Data for rice were averaged over 3 years and data for other crops were averaged over 2 years.
[2] Controls 1 and 2 were non-steamed and steamed soils, respectively.

Table 3: Response of Populations of *Rotylenchulus reniformis* on Soybean and Cotton to application of Agri-Terra™, Telone II, and Methyl Bromide.[1]

| Nematicide Treatment | SOYBEAN | | | COTTON | | |
|---|---|---|---|---|---|---|
| | **(Preplant)** | **(Mid-Season)** | **(Harvest)** | **(Preplant)** | **(Mid-Season)** | **(Harvest)** |
| Agri-Terra™ | 20,127a | 11,282c | 29,057b | 23,382a | 11,002c | 24,782c |
| Telone II | 21,386a | 28,528b | 31,641b | 16,638a | 40,575b | 63,662b |
| Methyl Bromide | 19,783a | 9,388c | 23,061b | 19,007a | 28,551b | 43,096b |
| Non-treated Control | 25,718a | 52,637a | 87,533a | 18,584a | 91,786a | 146,031a |

[1] Data are numbers of nematodes per 500 cc of soil and values within columns followed by the same letter were not significantly different and were averaged over the years 2000 and 2002.

Table 4: Performance of Agri-Terra™ in Field Trials in Louisiana with Cotton and Soybean (2000-2003)[1].

| Year | SOYBEAN[2] Agri-Terra™ | SOYBEAN[2] Non-Treated Control | COTTON[3] Agri-Terra™ | COTTON[3] Non-Treated Control |
|---|---|---|---|---|
| 2000 | 15.0a | 15.2a | 5.1a | 2.7b |
| 2001 | 10.2a | 6.4b | 6.7a | 3.0b |
| 2002 | -- | -- | 10.2a | 5.6b |
| 2003 | 9.6a | 3.8b | 3.7a | 1.8b |
| Average | 11.6a | 8.4b | 6.4a | 3.2b |

[1] Data were collected at harvest and are means of 6 replications. For each crop, values across rows followed by the same letter are not significantly different.
[2] For soybean, data are Kg. of seed harvested per 36.9 meters (center 2 rows of each plot).
[3] For cotton, data are Kg. of seed cotton harvested per 55.4 meters (center 2 rows of each plot).

Table 5: Effect of Agri-Terra™ on Sugarcane Yield Components at Harvest in 2002 and 2003 in a Field Trial Conducted at the LSU AgCenter Sugar Research Station.[1]

| | PLANT CANE CROP (2002) | | | FIRST RATOON CROP (2003) | | |
|---|---|---|---|---|---|---|
| Nematacide Treatment | Sugar per ton (lbs) | Tons cane per acre | Sugar per acre (lbs) | Sugar per ton (lbs) | Tons cane per acre | Sugar per acre (lbs) |
| Agri-Terra™ Once[2] | 178ab | 40.9ab | 7374a | 189a | 32.9a | 6230a |
| Agri-Terra™ Twice[3] | 157c | 41.3ab | 6476a | 172b | 31.9a | 5494a |
| Control[4] | 163bc | 44.7a | 7309a | 174b | 32.0a | 5544a |

[1] Values within columns followed by the same letter were not significantly different. Data collected by Dr. J.W. Hoy; Professor, LSU Department of Plant Pathology and Crop Physiology.
[2] Agri-Terra™ once at planting. [3] Agri-Terra™ at planting and the following spring. [4] Non-treated.