MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

2014 REPORT OF THE METHYL BROMIDE TECHNICAL OPTIONS COMMITTEE

2014 Assessment

United Nations Environment Program
Montreal Protocol on Substances that Deplete the Ozone Layer

United Nations Environment Programme (UNEP)
2014 Report of the Methyl Bromide Technical Options Committee

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The text of this report is composed mainly in Times New Roman.

Composition of the Report: Methyl Bromide Technical Options Committee

Coordination: Marta Pizano, Mohammed Besri, Ian Porter, MBTOC Co-Chairs.

Final editing and layout: Marta Pizano, Ian Porter, Mohamed Besri, MBTOC Co-Chairs

Reproduction: UNEP/ Ozone Secretariat, Nairobi
Date: February, 2015

Under certain conditions, printed copies of this report are available from:

United Nations Environment Programme
Ozone Secretariat
P.O. Box 30552
Nairobi, Kenya

This document is also available in portable document format from:

http://ozone.unep.org/Assessment_Panels/TEAP/Reports/MBTOC/index.shtml

ISBN: 978-9966-076-08-3

Methyl Bromide Technical Options Committee:

Co-Chairs: Mohamed Besri (Morocco); Marta Pizano (Colombia); Ian Porter (Australia)

Members: Jonathan Banks (Australia), Chris Bell* (UK), Fred Bergwerff (The Netherlands), Aocheng Cao (China), Peter Caulkins* (USA), Ricardo Deang* (Philippines), Raquel Ghini (Brasil), Ken Glassey (New Zealand), Alfredo Gonzalez (Philippines), Michelle Marcotte* (Canada), Takashi Misumi (Japan), David Okioga* (Kenya), Christoph Reichmuth (Germany), Jordi Riudavets (Spain), John Sansone* (USA), Sally Schneider* (USA), JL Staphorst (South Africa), Akio Tateya (Japan), Robert Taylor* (UK), Alejandro Valeiro (Argentina), Ken Vick (USA), Nick Vink (South Africa), Chris Watson* (UK), Jim Wells* (USA), Eduardo Willink (Argentina), Suat Yilmaz (Turkey).

* Retired from MBTOC December 31st, 2014.

In memoriam – Antonio Bello Pérez

MBTOC meeting (soils group), Alassio, Italy, August 2008

Antonio Bello is third from the left

Shortly after finishing this Assessment Report, our colleague and great friend, Professor Antonio Bello (CSIC, Madrid, Spain), former member of MBTOC, passed away. This is a shock and a very sad event for the MBTOC family. For many years, Antonio was a pillar of MBTOC. His research on alternatives to MB, particularly on biofumigation, not only made a great contribution to MB phase-out, but also provides a sustainable option with large benefits for the future of our planet. Antonio committed his life to science, to the protection of the ozone layer and to making the world a better place for future generations. In Antonio, we have lost a great scientist and unforgettable friend. He was a wise man who selflessly shared his knowledge with anyone asking for his advice. We will always keep him in our thoughts and prayers and we will never forget Antonio's generosity, graciousness and kindness. Rest in peace our beloved friend.

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Glossary of Acronyms

1,3-D	1,3-Dichloropropene
A5	Article 5 Party
AITC	Allyl isothiocyanate
ASD	Anaerobic soil disinfestation
CUE	Critical Use Exemption
CUN	Critical Use Nomination
DOI	Disclosure of Interest
EDN	Ethylene dinitrile
EU	European Union
EPA	Environmental Protection Agency
EPPO	European Plant Protection Organisation
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
ISPM	International Standard Phytosanitary Measure
LPBF	Low Permeability Barrier Film (including VIF films)
MB	Methyl bromide
MBTOC	Methyl Bromide Technical Options Committee
MI	Methyl iodide
MITC	Methyl isothiocyanate
MOP	Meeting of the Parties
MS	Metham sodium
Non-A5	Non Article 5
NPPO	National Plant Protection Organisation
OEWG	Open Ended Working Group
Pic	Chloropicrin
QPS	Quarantine and Pre-shipment
SF	Sulfuryl fluoride
TEAP	Technology and Economics Assessment Panel
TIF	Totally Impermeable Film
USA	United States of America
VIF	Virtually Impermeable Film
VOC	Volatile Organic Compound
WMO	World Meteorological Organisation

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Chapter 1. Executive Summary

1.1. Mandate and report structure

Under Decision XXIII/13 taken at the Twenty-Third Meeting of the Parties to the Protocol in 2011, the Parties requested the Assessment Panels to update their 2010 reports in 2014 and submit them to the Secretariat by 31 December 2014 for consideration by the Open-ended Working Group and by the Twenty Seventh Meeting of the Parties to the Montreal Protocol, in 2015.

As required under Decision XIII/13, the MBTOC 2014 Assessment reports on advances since 2010 to replace Methyl Bromide (MB) used under Critical Use by non-Article 5 Parties and continued reduction in methyl bromide use in Article 5 countries to meet the required phase out schedule in 2015 with specific reference to challenges associated to the phase-out and its sustainability. It also reports on QPS uses, which are presently exempt from controls under the Montreal Protocol. It reports on technically and economically feasible alternatives for non-QPS and QPS uses of MB and gives actual examples of their successful commercial adoption around the world. It shows trends in methyl bromide production and consumption in both Article 5 and non-Article 5 Parties, estimated levels of emissions of MB to the atmosphere, and strategies to reduce those emissions.

1.2. The Methyl Bromide Technical Options Committee (MBTOC)

As at December 2014, MBTOC had 29 members: 12 (41%) from Article 5 parties and 17 (59%) from non-Article 5 parties. Members came from 7 Article 5 and 9 non-Article 5 countries. After the renomination process in 2014 MBTOC numbers have reduced to has twenty members in 2015, 10 from Article 5 and 10 from non-Article 5 Parties.

1.3. Methyl bromide control measures

Methyl bromide was listed under the Montreal Protocol as a controlled ozone depleting substance in 1992. Control schedules leading to phase-out were agreed in 1995 and 1997. There are a number of concerns apart from ozone depletion that also led countries to impose severe restrictions on methyl bromide use including toxicity to humans and associated operator safety and public health, and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by methyl bromide and its derived bromide ion are also of concern.

The control measures, agreed by the Parties at their ninth Meeting in Montreal in September 1997, were for phase out by 1 January 2005 in non-Article 5 countries and for Parties operating under Article 5 of the Protocol (developing countries) a 20% cut in production and consumption, based on the average in 1995-98, from 1 January 2005 and phase out by 1 January 2015. Since 2003, nine non-Article 5 Parties have submitted nearly 150 applications for 18,700 tonnes for'critical uses' after 2005 for non-QPS purposes under Article 2H of the Montreal Protocol.By 2014 the number had declined to three applications for 267 tonnes for use in 2016. Use of methyl bromide under the 'Critical Use' provisions is available to 'Article 5 countries after 2015 and accordingly in 2014 three Article 5 Parties submitted six nominations for use of 500 tonnes in 2015.

Although QPS uses must be officially reported under Article 7 of the Protocol they continue to be exempt from controls under Article 2H.

1.4. Production and consumption trends

At the time of writing this report, all Parties had submitted data to the Ozone Secretariat for controlled uses in 2013. Although a few cases of data gaps remain from past years, reported data is much more complete than in the past. All tonnages are given in metric tonnes in this report.

In 2013, global *production* for the methyl bromide uses controlled under the Protocol was 2,493 tonnes, which represented 9% of the 1991 reported production data (66,430 tonnes). Less than 0.5% of production occurred in Article 5 countries.

Global *consumption* of methyl bromide for controlled uses was reported to be 64,420 tonnes in 1991 and remained above 60,000 tonnes until 1998. Global consumption was estimated at 8,148 tonnes in 2009 and declined to about 2,953 tonnes in 2013. Historically, in non-Article 5 regions, about 91% of methyl bromide was used for pre-plant soil fumigation and about 9% for stored products and structures.

The official aggregate baseline for non-Article 5 countries was about 56,083 tonnes in 1991. In 2005 (the first year of critical use provisions), non-Article 5 consumption had been reduced to 11,470 tonnes, representing 21% of the baseline. Many non-Article 5 countries achieved complete phase out for controlled uses before 2009 (New Zealand, Switzerland and countries of European Community), the two latter Parties for all uses by 2011. Israel and Japan phased out for controlled uses in 2011 and 2012 respectively (for preplant soil uses). For the remaining uses phase-out or substantial reductions have occurred in most sectors; the USA, which was the largest non QPS user of MB historically, has indicated that 2016 will be the last year of MB for its remaining preplant soil use in the strawberry fruit sector. Many Article 5 Parties previously included among the largest users now report complete phase-out (i.e. Brazil, Turkey, Lebanon, Zimbabwe, Morocco). Other Article 5 Parties have made very significant reductions in their consumption since 2005 and aggregate consumption is now at 14% of the baseline (86% has been replaced).

In 2014, the Meetings of the Parties approved CUEs of 485.589 tonnes for use in 2016 in three non-Article 5 Parties and 333.257 tonnes for 2015 in Article 5 Parties.

1.4.1. Consumption trends at national level

In 1991 the USA, European Community, Israel and Japan used nearly 95% of the methyl bromide consumed in non-Article 5 countries. In 2013 permitted levels of consumption (for CUEs) in these four Parties was 2.2%, 0% and 0% and 3.3% of their respective baselines, although in 2014 Japan reached total phase out.

The Article 5 consumption aggregate baseline is 15,870 tonnes (average of 1995-98), with peak consumption of more than 18,100 tonnes in 1998. Many Article 5 countries increased their methyl bromide use during the baseline years. Total Article 5 consumption reduced to 2,276 tonnes in 2013, which is 14% of the baseline. A MBTOC survey of ozone offices, regional networks and national experts in 2014 provided information on the breakdown of methyl bromide uses in major methyl bromide-consuming countries. In 2013, an estimated 93% was used for soil and 7% for commodities/structures, not including QPS, in Article 5 regions. Since soil uses of methyl bromide have predominated historically, the reduction in consumption of methyl bromide for soil fumigation has been the major contributor to the overall reduction in global consumption of methyl bromide. Consumption of methyl bromide for structural and commodity purposes has also declined significantly.

The vast majority of Article 5 parties achieved the national freeze level in 2002. In 2005, 94% of Article 5 parties (136 out of 144) either reported zero consumption or achieved the 20% reduction step by the required date; and in many cases they achieved this several years earlier than required by the Protocol. Presently, all Article 5 Parties are in compliance with this reduction step. Fifty-six Article 5 parties (38%) have never used MB or reported zero MB consumption since 1991. The total number of Article 5 parties that have consumed MB (currently or in the past) is 91, or 62% of the total 148 Article 5 parties. Of the 91 MB-user countries, 73 (80%) have phased out MB, and only 18 still reported consumption in 2013.

1.5. Alternatives to methyl bromide

MBTOC assumes that an alternative (Refer Decision IX/6 1(a)(ii)) demonstrated in one region of the world would be technically applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex. Additionally, it is recognised that regulatory requirements, or other specific constraints may make an alternative available in one country but unavailable in another specific country or region. When evaluating CUNs, MBTOC accounts for the specific circumstances of each Party.

MBTOC was able to identify alternatives for over 98% by mass of controlled uses in 2013.

1.5.1. Impact of registration on availability of alternatives

MBTOC considers that technical alternatives exist for almost all remaining controlled uses of methyl bromide. However regulatory or economic barriers may exist that limit the implementation of some key alternatives and this can affect the ability to completely phase-out methyl bromide in some countries.

Chemical alternatives in general, including methyl bromide, have issues related to their long-term suitability for use. In the EU, methyl bromide use was completely stopped (for all uses including QPS) in 2010, mainly due to health issues; in the USA and several other countries, methyl bromide and most other fumigants are involved in a rigorous review that could affect future regulations over their use. Thus, consideration of the long-term sustainability of treatments adopted as alternatives to methyl bromide is still vitally important; both chemical and non-chemical alternatives should be considered for adoption for the short, medium term and longer term.

1.5.2. Alternatives for soil treatments

The reduction in consumption of methyl bromide for soil fumigation has been the major contributor to the overall reduction in global consumption of methyl bromide for controlled uses with amounts used in 2013 falling 85% from about 57,400 tonnes in 1992 to less than 450 tonnes, in non-Article 5 Parties and about 2,210 tonnes in Article 5 Parties.

The main crops for which methyl bromide is still being used in non-Article 5 countries are strawberry fruit, and strawberry runners. Some uses previously considered under the CUN process have been partially reclassified as QPS (e.g. forest nurseries). Crops still using methyl bromide in 2013 in Article 5 Parties included cucurbits, strawberry fruit, ginger, nurseries (strawberry and raspberry runners) tomatoes and other vegetables.

Since the 2010 MBTOC Report, adoption of chemical and non chemical alternatives to replace methyl bromide as a pre-plant soil fumigant has shown significant progress, particularly due to improved performance of new formulations of existing chemical fumigants (1,3 D/Pic, Pic alone, metham sodium) and new fumigants (ie dimethyl disulfide), but also due to increased uptake of non chemical alternatives i.e. grafted plants on resistant rootstocks, improved steaming methods, substrate production, biofumigation.

In 2008, a one to one replacement to MB, iodomethane (methyl iodide) was registered in several countries (USA, New Zealand), however the manufacture of this fumigant was withdrawn in 2012. Dimethyl disulfide (DMDS) is now registered in the USA (not California) and other countries. The world has seen an increase in regulations on alternatives, with tighter regulations on all fumigants particularly in the EU.

1.5.2.1. Chemical alternatives

The following fumigants are currently available in many regions and are the main alternatives that have been adopted as alternatives for MB.

- Chloropicrin (trichloronitromethane) (Pic), which is effective for the control of soilborne fungi and some insects and has limited activity against weeds. Combination with virtually or totally impermeable films (VIF, TIF) is an effective strategy to reduce application rates keeping satisfactory efficacy.
- 1,3-Dichloropropene (1,3-D), which is used as a nematicide and also provides effective control of insects and suppresses some weeds and pathogenic fungi. 1,3- D as a single application has no effect in controlling fungi or bacteria, for this reason it is often combined in mixed formulations with chloropicrin. As with chloropicrin, 1,3-D can be combined with virtually or totally impermeable films (VIF, TIF) with satisfactory efficacy.
- Fumigants which are based on the generation of methyl isothiocyanate (MITC), e.g. dazomet, metham sodium and metham potassium, are highly

effective at controlling a wide range of arthropods, soilborne fungi, nematodes and weeds, but are less effective against bacteria and root-knot nematodes. For this reason their use is often found in combination with other chemical treatments or IPM controls. The efficacy of MITC against fungal pathogens is variable, particularly against vascular wilts.

- Dimethyl disulfide (DMDS), which has been registered recently, appears to be highly efficient against various nematodes, including *Meloidogyne* spp, but is less effective on fungal pathogens. Again, DMDS is more effective when combined with VIF or TIF films.
- Isothiocyanates (ITCs) are sulfur-containing compounds produced by many members of *Brassicaceae* plant family, showing insecticidal and herbicidal activity. Research has demonstrated that they can be used as a pre-plant soil fumigant alternative for broad-spectrum control of weed seeds, nematodes and diseases. Allyl isothiocyanate (AITC) was registered in the USA in September 2013 (but not in California) for many types of vegetables and turf. Its small buffer zone requirement gives it an advantage over other fumigants. AITC is expected to be registered in the near future in other countries including Mexico, Canada, Italy, Spain, Turkey, Morocco, Japan and Israel.
- Sulfuryl fluoride (SF) is an insecticide fumigant gas, widely used for insect and rodent control in post-harvest commodities and structures. SF was registered in China as a nematicide fumigant for cucumber in 2014. This fumigant has a shorter plant-back time than other fumigants including MB and can be applied when soil temperatures are low. These features give this fumigant a significant advantage over other soil fumigants.
- Trials with other chemicals such as abamectin, fluensulfone and certain fungicides are also providing promising options for soilborne pest and disease management in several countries.

The future of soil disinfestation lies in combining available fumigants with other methods, or other fumigants and non-chemical fumigants to obtain acceptable performance. Combined fumigant treatments can expand the pest control spectrum and lead to performance levels that match and even surpass those of MB. Examples include 1,3-D/Pic, 1,3-D or 1,3-D/Pic and MITC, DMDS + Pic and others.

Lack of registration of some MB alternatives as well as regulatory constraints have hampered MB phase-out in some countries where MB is still being used under a critical use exemption.

1.5.2.2. Non chemical alternatives

- Grafting, resistant rootstocks and resistant varieties are increasingly used to control soilborne diseases in vegetables, particularly tomatoes, cucurbits, peppers and eggplants in many countries. They are generally adopted as part of an integrated pest control system, or combined with an alternative fumigant or pesticide, and have led to the reduction or complete replacement of methyl bromide use in several sectors in different countries. Recent studies focus on improving the tolerance of vegetables to abiotic stresses including soil salinity, drought, heavy metals, organic pollutants and low and high temperatures.
- Soilless culture is a rapidly expanding cropping practice worldwide, primarily for protected agriculture, which has offset the need for methyl bromide, especially in some flower crops, vegetables and for seedling production including forest seedlings. In particular, flotation systems, based on soilless substrates and

hydroponics, have replaced the majority of the methyl bromide for tobacco seedling production worldwide. This growing system can be used in combination with other options, for example compost, grafted plants and/ or biocontrol agents, providing very good results.

- Steam disinfestation is an increasingly attractive strategy to control soilborne pathogens and weeds both in greenhouses and field crops. New developments of steam application methods are aimed at reducing costs and extend its use on crops grown outdoors. Development of more efficient and economic steam application equipment, currently in progress, suggests that steam is approaching wider commercial feasibility.
- Solarisation is now increasingly combined with biofumigation or low doses of fumigants, as part of IPM programs to replace MB for controlling soilborne pathogens and weeds in many crops including vegetables and ornamentals with excellent results.
- Anaerobic soil disinfestation (ASD) is a biologically based, non-fumigant, pre-plant soil treatment developed to control a wide range of soilborne plant pathogens and nematodes in numerous crop production systems used for example in Japan, The Netherlands and the USA. Commercial use of ASD is currently limited by cost and uncertainty about its effectiveness for controlling different pathogens across a range of environments. Its feasibility is largely impacted by moisture and availability of appropriate carbon sources. However, active research is underway to adjust this promising option.

1.5.2.3. Combination of chemical and non chemical alternatives

The combination of chemical with a range of non-chemical alternatives continues to expand as effective strategies to overcome problems due to the narrow spectrum of activity of some single control methods. The efficacy of grafted plants for example, can be greatly enhanced by combining it with solarisation and biofumigation, green manures, and chemicals such as MITC generators, 1,3-D and non- fumigant nematicides. Combinations of fumigant alternatives (1,3-D/Pic, MNa/Pic) with LPBF or relevant herbicides have been shown to be effective for nutsedge (*Cyperus* spp.). Finding alternatives for nursery industries has proven more difficult as growers are uncertain of the risk of spread of diseases provided by the alternative products. Further, regulators often lack the data to determine if alternatives meet the quality standards (e.g. certification requirements).

Crop specific strategies implemented in non-Article 5 and Article 5 regions are discussed in detail in the 2014 Assessment Report. These include alternatives used for the key sectors where it was necessary to phase-out methyl bromide in specific climates, soil types and locations, as well as application methods and other considerations.

1.5.2.4. Alternatives for strawberry runners

In 2014, MB is still used in three non-A5 Parties either as a critical use (Australia, Canada) or under a QPS exemption (USA). Mexico is continuing use in 2015 and under a critical use exemption, but trials with alternative fumigants (1,3-D/Pic, metham sodium) are giving encouraging results.

In Australia, the northern production region fully transitioned in 2009 to mixtures of 1,3-D/Pic and Pic alone, however in the cooler southern regions in heavy soil types these alternatives are phytotoxic causing losses of up to 40%, or are ineffective and no alternatives have been adopted except for the use of substrate production of foundation stock. The industry does, however, produce its early generations of runners using soil less culture, which reduces the need for disinfestation with MB/Pic. This system is not economically feasible for later generations..

In Canada in 2008, several regions transitioned to alternatives mainly Pic alone, however owing to its lack of registration in Prince Edward Island the request for a critical use continues.

In the EU (France, Italy, Poland, Spain), growers are using improved application techniques for old fumigants, such as metham sodium and dazomet to grow runner plants.In some countries where MB has been phased-out, there have been market shifts where growers may produce their own plants or where industries import runners produced in other countries.

1.5.3. Alternatives for treatment of post-harvest uses: food processing structures and durable commodities (non-QPS)

Parties and scientists around the world continue to conduct research aimed at identifying and adopting alternatives to MB for controlling pests causing problems in the structures and commodities sectors. However, as of 2015, all postharvest uses of MB have been phased out in non-A5 Parties and no CUNs have been submitted for these uses for 2016. Some small usage for structures (flour mills), grain and dried foodstuffs remained in Article 5 Parties in 2013.

The main alternatives to the disinfestation of flourmills and food processing premises are sulfuryl fluoride (including combinations of SF and heat) and heat (as full site or spot heat treatments). Some pest control operators report that full control of structural pests in some food processing situations can be obtained without full site fumigation through a more vigorous application of IPM approaches. Other pest control operators report success using a combination of heat, phosphine and carbon dioxide.

Phosphine fumigation has emerged as the leading treatment of infested commodities. Although phosphine is the fumigant of choice to replace MB in many postharvest treatments, some problems with its use need attention, particularly the possible development of resistance in the pests to be controlled.

Treatment of commodities with sulfuryl fluoride has also expanded. The fumigant is used for the treatment of grain, cotton and timber. The substance is also used for disinfestation of museums in the USA. SF is in use for disinfestations of museums (structures) against insect pests in Japan. SF is now intensely used for disinfestation of bulk grain in Australia, also for resistance management of phosphine. China has three factories producing SF for local use and export.

1.5.3.1. Regulatory considerations

Many commercial companies have undertaken significant efforts and Parties to conduct research, apply for registration, and register alternatives to optimize their legal use. The registration of chemicals for pest control, including MB, is however under continuous review in many countries.

Additional registration issues arise where treatments will be used on food commodities or where treatments used in food processing buildings might transfer residues to food because the maximum residue limits (MRLs) for the residual chemicals must also be registered in importing countries.

1.5.3.2. Update on progress in research into methyl bromide alternatives

Many avenues of research have been pursued in the attempt to find realistic alternatives to MB for the remaining commodity and structural treatments conducted worldwide, as well as and in quarantine or preshipment. These include studies on alternative fumigants such as phosphine, sulphuryl fluoride and ozone, on controlled atmospheres with elevated temperature or raised pressure, on microwave, radio frequency or ionizing radiation, or on heat. Carbon dioxide and ethyl formate is also considered as an alternative chemical for disinfestation.

1.5.3.3. Alternatives to methyl bromide for treating dates

Pest infestations in the field pose serious post harvest problems for all date varieties. Historically, dates have been disinfested prior to storage with ethyl formate, ethylene dibromide or ethylene oxide, and more recently with MB. Fumigation with MB forces a high proportion of larvae and adults to emigrate from the fruit before they succumb, which is essential to meet some religious and food quality requirements. The specific situation of high moisture dates, at one point indicated as critical in A5 countries producing dates is now considered resolved. Phosphine fumigation, supplied by tablet formulations or a phosphine generator has largely replaced post harvest MB fumigation in Algeria, Tunisia, Egypt, Jordan, UAE, KSA and other countries.

1.5.3.4. Dry cure pork product in SE USA – the remaining MB critical use in non-A5 Parties

Natural pork products are subject to pest infestation, in part because of the lengthy storage time required for flavour development. The pests most commonly reported are red-legged ham beetles *Necrobia rufipes* and ham mites *Tyrophagus putrescentiae.* Although pest control is being achieved without MB in many countries producing cured ham products, particular conditions present in the USA have made this use very difficult to replace.

Mites are acknowledged to be very difficult to kill with phosphine, and in tests of the effectiveness of SF in 2008, control of the ham mites required three times the US legal limits of SF. Extensive research is under way indicating that the active ingredients that show the most promise as potential methyl bromide alternatives are propylene glycol, butylated dhydroxytoluene (BHT), and lard. Propylene glycol (PG) is likely the most feasible food-grade ingredient that could be used to control ham mites but is relatively expensive. Currently, no fully effective treatment has been found which controlled the target pests at commercial scale for Southern cured pork production. MBTOC's review and analysis indicates merit for further research and refinement by pest control fumigators, and in particular for improving the efficacy of SF fumigations as methyl bromide replacements.

1.5.3.5. Special review on controlling pest eggs with sulfuryl fluoride

Fumigation with SF is one of the pest control methods adopted by some parties as the principal alternative to methyl bromide in some major postharvest and structural uses. The lack of full effectiveness of SF against eggs of pests is mentioned in several critical use nominations. MBTOC collated available data on the fumigation of eggs of stored product insects and especially those occurring in rice and flourmills, the situations of particular concern where SF is a potential or actual methyl bromide replacement. Summaries of published mortality data and lethal responses of eggs of 28 economically important insects and mites following fumigation with sulfuryl fluoride at 20°C are included. Pest species are sorted into groups that are probably, possibly or unlikely to be controlled at 1,500 g h m^{-3} at at 26.7°C (80°F) and 24 h exposure. This ct-product is the maximum rate that is allowed under the registration of SF as a pesticide ('label' rate) for control of all developmental stages of stored product pest, such as specified in the 'Fumiguide', a proprietary guide to the use of SF as a postharvest and structural fumigant.

1.5.3.6. Other alternatives

Research on the use of propylene oxide and ethyl formate as methyl bromide continues and these chemicals are being adopted in several countries. Other chemical options include methyl iodide, MITC and CO_2, ozone, nitric oxide, and carbonyl sulfide (COS).

Adoption of Controlled Atmospheres (CA) and Modified Atmospheres (MA) as a means to control pests in stored commodities continues to increase. CA and MA treatments offer large commercial and small packing houses, even farmers, effective postharvest pest control options useful for most durable commodities (and even non-food commodities such as museum and historical artifacts), under a very wide range of circumstances, without using chemical fumigants. The CA treatment is based on creating a low-oxygen environment within a structure causing death of pests.

The use of irradiation as a phytosanitary treatment has increased with an undetermined part of this volume directly replacing methyl bromide fumigation. In 2013, about 5,800 tonnes of fresh fruit were irradiated for import into the US.

In Europe - especially in Germany - and in the US, parasitic wasps and predators now comprise a significant parts of pest management programs for facilities and stored products. Heat, cold and essential oils, are further options being researched and for which adoption has occurred around the world.

1.5.3.7. Integrated Pest Management

IPM is a sustainable pest risk management approach combining biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks. A reduction in use of pest control chemicals in food processing, and using less toxic chemicals is a goal of most IPM practitioners. Modern strategies concentrate on approaches where the infestation itself is limited at an early stage to prevent later mass growth and necessities for acute and immediate control. Biological control addresses the need of finding ways to attack the first intruders into a storage system.

1.6. Alternatives to methyl bromide for quarantine and pre-shipment applications (exempted uses)

Article 2H exempts methyl bromide used for QPS treatments from phase-out for quarantine and pre-shipment purposes. Methyl bromide fumigation is currently often a preferred treatment for certain types of perishable and durable commodities in trade worldwide, as it has a well-established, successful reputation amongst regulatory authorities.

QPS uses are usually for commodities in trade, but one Party has classified some preplant soils uses of methyl bromide as quarantine uses. Similar uses by other Parties have remained under controls of the Montreal Protocol and have or are being phased out. Alternatives to these uses are discussed in detail in Chapter 5 on alternatives for pre-plant soil fumigation.

Quarantine treatments are generally approved on a pest and product specific basis, and following bilateral negotiations, which may require years to complete. This process helps ensure safety against the incursion of harmful pests.. For this and other reasons, replacing methyl bromide quarantine treatments can be a complex issue. Many non-methyl bromide treatments are, however, published in quarantine regulations, but they are often not the treatment of choice. Nevertheless, partial or complete adoption of alternatives to methyl bromide for QPS has occurred since the 2010 MBTOC Assessment Report. The European Community banned all uses of methyl bromide in its 27 member states including QPS, as of March 2010. Other countries show significant reductions in their methyl bromide consumption for QPS. In response to Decisions XX/6 and XXI/10 MBTOC estimated that between 31 and 47% of the MB used for QPS purposes could be replaced with immediately available alternatives.

Global production of methyl bromide for QPS purposes in 2013 was 9,915 tonnes, increasing by about 12% from the previous year. Production occurs in four parties, USA, Israel, Japan and to a much lesser extent, China. Although there are substantial variations in reported QPS production and consumption on a year-to-year basis, there is no obvious long-term increase or decrease.

QPS consumption has remained relatively constant over the last decade. In 2009 the QPS use exceeded non-QPS for the first time, being 46% higher. This was partly due to the continued decrease in the non-QPS uses, as well as recategorisation by some Parties of uses previously considered non QPS to QPS. For example since 2003 an amount of methyl bromide included in the initial baseline estimates for controlled MB uses, between 1400 to 1850 t, has been recategorised to QPS MB use for the preplant soil treatment of propagation material. In 2013, reported QPS consumption was over three times larger than controlled consumption.

In 2013, QPS consumption in A5 Parties (5,521 tonnes) represented 56% of global consumption; non-A5 Party consumption, at 4,307 tonnes was 46%. Overall, consumption in Article-5 Parties has trended upward over the past 15 years, whereas consumption in non-A5 Parties. Global consumption averaged 10,850 tonnes over the period 1999 to 2013 and in 2013 (9,830 tonnes) remained close to the average.

On a regional basis, consumption in the Latin America & Caribbean, Africa and Eastern Europe regions has remained much lower since 1999 than in Asia and North America. In 2013, an analysis of global consumption (including both A5 and non-A5 Parties in the regions where appropriate), Asia accounted for 47% of global QPS consumption.

While there remain some data gaps and uncertainties, information supplied by the Parties allowed MBTOC to estimate that four uses consumed more than 80% of the methyl bromide used for QPS in 2008: 1) Sawn timber and wood packaging material (ISPM-15); 2) Grains and similar foodstuffs; 3) Pre-plant soils use; 4) Logs; and 5) Fresh fruit and vegetables. On the basis of these estimates and currently available technologies to replace methyl bromide for QPS, MBTOC calculated that about 31% of global consumption.

Because it is approved by IPPC for compliance to ISPM-15, the main adopted alternative to methyl bromide for wood packaging material is heat (now including dielectric heating); non-wooden pallets provide an additional option. Alternatives for logs include phosphine, sulfuryl fluoride, EDN (cyanogen) and other alternative fumigants; heat, irradiation and water soaking (immersion) and debarking provide further options. Methyl bromide used as a quarantine treatment in grains and similar foodstuffs could be replaced by alternative fumigants (phosphine, sulfuryl fluoride), by controlled atmospheres or by temperature treatments (heat or freezing). Preshipment treatments in grains and similar foodstuffs could be replaced by fumigants, protectants, controlled atmospheres and integrated systems. For pre-plant soil treatments, alternative fumigants are available, provided the alternatives meet certification standards; substrates may be used at least partially in the propagation systems.

For perishables, there are various approved treatments, depending on product and situation, including heat (as dry heat, steam, vapour heat or hot dipping), cold (sometimes combined with modified atmosphere), modified and controlled atmospheres, alternative fumigants, physical removal, chemical dips and irradiation. In 2013, about 5,800 tonnes of fresh fruit were irradiated for import into the US, representing a dramatic increase of 6,500% over usage of this technique in 2007.

The technical and economic feasibility of alternatives to methyl bromide used for QPS in all countries mainly depend on the efficacy against quarantine pests of concern, the infrastructural capacity of the country, end-use customer requirements, phytosanitary agreements where relevant, and logistical requirements and regulatory approval for the use of the alternative. In the absence of regulatory or economic incentives to adopt alternatives and assuming methyl bromide is in most cases the lowest cost effective system at present, an alternative would not be voluntarily adopted unless it performed as well or better at the same market cost. Technically feasible alternatives will have limited market acceptance if they are more costly – and in the world of bulk commodities, it is difficult to entice end buyers to pay a higher price for goods treated with alternatives.

1.7. Progress in phasing-out methyl bromide in Article 5 parties

Progress made in phasing out controlled uses of methyl bromide in Article 5 countries is addressed in view of the phase-out date of 1st January 2015. Challenges and factors that could potentially put the sustainability of the phase-out at risk are analysed together with the major technologies implemented and the factors that have assisted MB phase-out in MLF projects and other efforts to replace MB.

By end of 2013 (the last date for which official data were available at the time of writing this report), about 86% of the controlled uses of MB in Article 5 Parties had been phased out. This was primarily achieved through MLF-funded projects implemented by the agencies of the Montreal Protocol, and has taken place at different rates in different regions. This chapter includes a list of the main types and objectives of such projects together with the main alternatives successfully replacing MB in different countries and regions.

The projects showed that for all locations and all crops or situations tested, one or more of the alternatives proved comparable to methyl bromide in their effectiveness in the control of pests and diseases targeted in the projects in these Article 5 countries.

By December 2014 the Multilateral Fund (MLF) had approved a total of 398 methyl bromide projects in more than 80 Article 5 Parties. This included 44 demonstration projects for evaluating and customising alternatives; 130 initiatives for the preparation of new projects, awareness raising, data collection, policy development and others; 95 technical assistance and training projects; and 129 investment projects for phasing-out methyl bromide.

MLF projects approved by December 2013 were scheduled to eliminate a total of 13,939 metric tonnes of MB in Article 5 countries. The total phase-out achieved by MLF projects by December 2013 was 12,165 tonnes (Table 7-3), which is 87% of the total due to be phased out by the projects, a figure which is higher than in previous years.

Projects have encouraged the combination of alternatives (chemical and non-chemical) as a sustainable, long-term approach to replacing methyl bromide. This has often implied that growers and other users change their approach to crop production or pest control and may even have to make important changes in process management. Adapting the alternatives to the specific cropping environment and local conditions (including economic, social and cultural conditions) is essential to success.

The projects showed that very large MB reductions are feasible over periods of 4 – 5 years, especially in cases where governments and MB users make constructive efforts to register, transfer and adopt existing alternatives, and where a full range of key stakeholders were involved. Early phase-out has brought by additional benefits to Article 5 Parties for example by improving production practices, making productive sectors more competitive in international markets and training large numbers of growers, technical staff and other key stakeholders.

Hurdles faced by Article 5 Parties include factors that go beyond the technical and economic feasibility of the alternatives including market drivers (ability to meet specific market windows), consumer issues, sufficient installed capacity to develop an implement an alternative and regulatory factors.

Challenges that may put the sustainability of the phase-out at risk include the continued unrestricted supply of MB in light of the exemption for QPS uses and the long term viability of some alternatives (for example when pests become resistant to an alternative or when regulations restrict the use of an alternative). Lack of registration of some alternatives are also an obstacle.

In accordance with Montreal Protocol controls, four Article 5 Parties have submitted CUNs for exemptions in 2015 and 2016.

1.8. Emissions from methyl bromide use and their reduction

Montreal Protocol restrictions on the use of MB are having greater impact on atmospheric MB than thought possible 10 years previously. The current understanding of the global annual budget (sources and sinks) for MB indicates that the global MB budget is not balanced and that there is potential for current identified sinks to exceed current identified sources by approximately 30 k tonnes. This implies that there may have been either large under reporting of MB production and consumption or that there are unidentified MB sources. Some of these may come from industrial processes, for example the production of purified tetraphthalic acid (PTA) or may be from unidentified natural sources. Resolving the current global budget imbalance requires a better understanding of the oceanic sources and sinks, industrial sources and natural vegetative sources of MB.

Overall total (natural and anthropogenic) MB emissions have declined from in excess of 120 k tonnes per year in 1995-1998 to 85 k tonnes in 2012, driven almost entirely by the declining consumption of non-QPS MB.

In 1995-1998, manufactured MB used in fumigation (48 k tonnes/year) accounted for about 40% of all identified MB sources; by 2012, thanks to countries taking steps to reduce the use of MB for non-QPS purposes, fumigation use had declined to just over 10% (10 k tonnes) of all identified sources, with QPS use accounting for about 8% of all identified sources. The total fumigation use of MB has declined by 80% over this period and the non-QPS fumigation use has declined by over 90%. The impact of the relatively recent and currently limited MB recapture on the global MB budget is likely to be small (less than 200 tonnes recaptured globally per annum (MBTOC estimate).

Owing to the short atmospheric half-life of MB (0.7 years) in the stratosphere, changes in emission of MB at ground level are rapidly reflected in changes in tropospheric and stratospheric MB concentrations.

The latest WMO scenarios suggest that further reductions in atmospheric concentrations are possible over the next few years, but will only occur if the remaining non-QPS uses in developing countries (A5 Parties) and the few non-A5 and A5 critical uses are phased out, and if emissions or use of MB for QPS are reduced significantly. In 2014, the use of MB for QPS was at least three times the total used for non-QPS in non-A5 and A5 countries.

Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere are estimated by MBTOC to be 41 – 91%, 85 - 98%, 76 – 88% and 90 - 98% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 67 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 77%.
Best estimates of annual MB emissions from fumigation use in 2013 of 8781 tonnes were 52% lower than in 2009, which totalled 17,041 tonnes.

Emission volume release and release rate to the atmosphere during soil fumigation depend on a large number of key factors. Of these, the type of surface covering and condition; period of time that a surface covering is present; soil conditions during fumigation; methyl bromide injection depth and rate; and whether the soil is strip or broadacre fumigated are considered to have the greatest effect on emissions.

Studies under field conditions in diverse regions, together with the large scale adoption of Low Permeability Barrier Films (LPBF), have confirmed that such films allow for conventional methyl bromide dosage rates to be reduced. Typically equivalent effectiveness is achieved with 25–50% less methyl bromide dosage applied under LPBF compared with normal polyethylene containment films.

Parties have been urged to minimise emissions of MB in situations where they still use MB and are unable to adopt non-ozone depleting alternatives. This includes both QPS treatments and fumigations carried out under CUEs (Decisions VII/7(c), IX/6). For QPS treatments, Decisions VII/5(c) and XI/13(7) urge Parties to minimize use and emissions of methyl bromide through containment and recovery and recycling methodologies to the extent possible.

Worldwide many fumigations continue to be conducted in poorly sealed enclosures, leading to high rates of leakage and gas loss. QPS treatments with MB could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment. For the 7,456 tonnes used for commodity and structural treatments, principally for QPS use, at 70% recapturable, 5,219tonnes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment.

At this time, there remain no processes for MB approved as a destruction process under Decision XV/9 and listed in any updates to annex II of the report of 15 MOP that listed approved destruction processes by source and destruction method. However, the situation is currently under review (Decision XXII/10).

There are now several examples of recovery equipment in current commercial use. All these units use are based on absorption of used methyl bromide on activated carbon or liquid scrubbing with nucleophilic reagents. Some are designed for recycling of the recaptured methyl bromide while others include a destruction step to eliminate the sorbed methyl bromide, thus minimising emissions. There is increasing adoption of these systems, though this has been driven by considerations other than ozone layer protection, e.g. occupational safety issues or local air quality. In the absence of regulations, companies reported they would not invest in the systems, because their competitors (who had not made the investment) would then have a cost advantage.

1.9. Economic criteria

During CUN evaluations, MBTOC assesses the financial feasibility of alternatives available to the Party (Decision IX/6), because an alternative may be considered technically feasible, but may not be economically feasible. Measurement of the economic implications of the use of methyl bromide or an alternative can in most cases be done satisfactorily by means of a partial budget analysis, a practical tool to compare alternative production practices.

2

Chapter 2. Introduction to the Assessment

2.1. Methyl Bromide

Methyl bromide (MB) is a fumigant that has been used commercially since the 1930's (Anon, 1994). It has been used to control a wide spectrum of pests including fungi, bacteria, soil-borne viruses, insects, mites, nematodes, rodents and weeds or weed seeds. MB has features that make it a versatile biocidal with a wide range of applications. In particular, it is a gas that is quite penetrative and usually effective over a broad range of temperatures. Its action is usually sufficiently fast and it airs rapidly enough from treated systems to cause relatively little disruption to crop production or commerce.

MB was listed under the Montreal Protocol as a controlled ozone depleting substance in 1992. Additional control schedules leading to phase-out for non quarantine and preshipment (QPS) uses (with specific exceptions) were agreed to in 1995 and 1997. Since 2005, exemptions have been allowed for 'Critical Uses' in non A5 Parties and will be allowed in 20015 for A5 Parties under Decision IX/6. Additionally some non A5 Parties have used small amounts of methyl bromide (< 20 t) after 2005 under the 'Emergency Use' provisions under Decicion IX/7 of the Montreal Protocol.

MB use for QPS treatments, where it performs a dual role for QPS treatments by facilitating trade as well as preventing the accidental import of exotic pests that can incur substantial costs for control and if possible eradication. The Protocol specifically excluded QPS from control measures in 1992 because at that time the Parties estimated that there were no alternatives to MB that gave the same level of protection for the diverse range of treatments carried out with this fumigant. Since this time, MBTOC and the QPS Taskforces have conducted several reviews for the Parties which demonstrate that alternatives are available for 31 to 47% of the uses of MB for QPS (TEAP, 2009c; 2010c), however no further controls have as yet been implemented.

A number of concerns over methyl bromide apart from ozone depletion have also led countries to impose severe restrictions on its use. These concerns include residues in food, toxicity to humans and associated operator safety, public health, and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by MB and its bromide ion are also concerns.

2.1.1. MB uses identified in Articles of the Protocol

MB is classified as a "controlled substance" under the Montreal Protocol (Article 1 and Annex E). The Articles of the Protocol refer to four main categories of MB uses, and each is subject to different legal requirements. Table 2-1 lists the four categories, and indicates those for which information is provided in this MBTOC report.

Two of the categories - the non-QPS fumigant uses and laboratory and analytical (L&A) uses - are subject to the phase-out schedules under Articles 2 and 5, with authorised Critical Use Exemptions (CUE). The phase-out schedules are summarized in Table 2-2 below. The other two categories of MB uses – QPS and feedstock used in industrial processes – are not subject to phase-out schedules but are subject to reporting requirements under the Protocol.

This report focuses primarily on the non-QPS and QPS fumigant uses. Feedstock is mentioned in this report only when discussing statistics on global MB production for all uses in Chapter 3. L&A uses are also included in general statistics on MB production in Chapter 3 but no breakdown is available. L&A uses are not discussed in MBTOC reports because they are assessed in the reports of the Chemical Technical Options Committee (CTOC).

Because the phase-out of controlled uses (non-QPS) of MB is now so well advanced – as of 1st January 2015 such uses are only authorised under the CUE process for both Article 5 and non-Article 5 Parties – QPS uses now comprise the largest category of MB use by the Parties of the Montreal Protocol (see Chapter 3). QPS us of MB has thus become the largest, non-controlled ODS emission (among the substances presently included in the Montreal Protocol).

TABLE 2-1. CLASSIFICATION OF MB USES UNDER THE MONTREAL PROTOCOL, INDICATING RELEVANT SECTIONS IN THIS ASSESSMENT REPORT

MB uses	Status under the Montreal Protocol	Relevant information in MBTOC Assessment
Non-QPS fumigant uses	Subject to production and consumption phase-out schedules of Articles 2 and 5, trade and licensing controls of Article 4, and data reporting requirements of Article 7. Critical Use Exemptions can be authorised by the MOP for specific uses that meet the criteria in Decision IX/6 and other relevant decisions in Article 5 and non-Article 5 Parties.	Chapters 1-3 and 5-9
QPS fumigant uses	Exempted from reduction and phase-out schedules. Subject to Article 7 data reporting requirements	Chapter 4 and several sections in chapter 6
Laboratory and analytical uses	Subject to production and consumption phase-out schedules of Articles 2 and 5 except for the specific Critical Use Exemptions under Decision XVIII/15. Subject to data reporting under Annex II of the Sixth Meeting of the Parties	L&A uses are covered in CTOC reports. Chapter 3 statistics on MB production include L&A, but no breakdown is available
Feedstock used in the manufacture of other chemicals	Exempted from phase-out schedule under Article 1. Subject to Article 7 data reporting requirements	Chapter 3 statistics on MB production

2.2. MBTOC mandate

The Methyl Bromide Technical Options Committee (MBTOC) was established in 1992 by the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer to identify existing and potential alternatives to MB. MBTOC, in particular, provides recommendations and advice to the Parties on the technical and economic feasibility of chemical and non-chemical alternatives for controlled uses of MB. Additionally, from 2003, MBTOC has had the task of evaluating Critical Use Nominations submitted by non- Article 5 Parties to the Montreal Protocol and by Article 5 Parties from 2014. MBTOC provides recommendations on such nominations, for review and endorsment by the Technology and Economic Assessment Panel (TEAP) and then consideration by the Parties. MBTOC presently works as a single committee and its members have distinct expertise in the uses of MB and its alternatives following areas: Soils (pre-plant fumigation), Structures and Commodities SC) and Quarantine and Pre-Shipment (QPS).

MBTOC is a subsidiary body of TEAP, the Panel that advises the Parties on scientific, technical and economic matters related to ozone depleting substances and their alternatives. Information contained in MBTOC's reports contribute to the Parties' deliberations on appropriate controls for MB and its alternatives and for endorsement of use by the Parties for critical uses. Parties review MBTOC and TEAP's recommendations and may accept, reject of modify these recommendations when taking decisions on CUE requests.

TABLE 2-2. PHASE-OUT SCHEDULES AGREED AT THE NINTH MEETING OF THE PARTIES IN 1997

Year	Non-Article 5 countries	Article 5 countries
1991	Consumption/ production baseline	
1995	Freeze	
1995-98 average		Consumption/ production baseline
1999	25% reduction	
2001	50% reduction	
2002		Freeze
2003	70% reduction	Review of reductions
2005	Phaseout with provision for CUEs	20% reduction
2015		Phaseout with provision for CUEs

Source: UNEP, Ozone Secretariat, 2015. Montreal Protocol Handbook.

Critical and emergency uses may be permitted after phaseout if they meet agreed criteria. Emergency uses may be of up to 20 metric tonnes.
Parties are urged to use stocks of MB for their critical uses. Such stocks need to be reported to the Ozone Secretariat.
Quarantine and pre-shipment (QPS) uses and feedstock are exempt from reductions and phaseout.

Decisions encouraging advanced phaseout:

- Countries may take more stringent measures than those required by the schedules (Article 2 of the Montreal Protocol).
- In applying the QPS exemption, all countries are urged to refrain from use of MB and to use non-ozone-depleting techniques wherever possible (Decisions VII/5 and XI/13).
- A number of developing and industrialised countries signed Declarations in 1992, 1993, 1995, 1997, 2003 and 2004 stating their determination to phase out MB as soon as possible.

2.3. Committee process and composition

At December 2014, MBTOC had 29 members; 17 (59%) from non-Article 5 and 12 (41%) from Article 5 Parties. These members came from seven Article 5 and nine non- Article 5 countries. Representation from diverse geographic regions of the world promotes balanced review and documentation of alternatives to MB, based on the wide-ranging expertise of Committee members. Many MBTOC members were nominated by their governments; however MBTOC co-chairs also have the authority to appoint members in full consultation with the focal points from their country of origin.

In accordance with new and revised Terms of Reference for TEAP and its Technical Options Committees, terms for all MBTOC members expired at the end of 2014 (Decision XXIII/10 (9)). Terms of service are now set at four years with the option of reappointment for ensuing terms. Several members have however resigned at the end of 2014, mostly non-A5 members who lacked the appropriate financial commitment from their Parties or other sources to attend MBTOC meetings. At and at the time of posting this report (February 2015) MBTOC membership stood at 20 members, 10 from Article 5 Parties, coming from nine countries and 10 members coming from seven non-Article Parties.

In accordance with the terms of reference of TEAP and TOCs, MBTOC members participate in a personal capacity as experts and do not function as representatives of governments, industries, non-government organisations (NGOs) or others (Annex V of the report of the 8th Meeting of the Parties). Members of MBTOC contribute substantial amounts of work in their own time. For construction of this Assessment Report, MBTOC met formally in Stellenbosch, South Africa (March, 2014) and Frankfurt, Germany (August, 2014). To produce each chapter as efficiently as possible, MBTOC sub-committees worked primarily on chapters covering their specific topics and topics affecting all chapters were discussed and agreed by the entire committee. Assessment structure and contents were agreed during these formal meetings. The Assessment was finalised by email, to produce a consensus document of the Committee.

MBTOC co-chairs and members working on this MBTOC 2014 Assessment Report are listed in Appendix 2. The co-chairs acted as coordinators and lead authors for the main chapters of this Assessment and members worked on those chapters most suited to their particular expertise.

2.4. UNEP Assessments

The first interim assessment on MB for the Protocol was completed in 1992. A full assessment of the alternatives to MB was completed in 1994 and reported to the Parties in 1995 (MBTOC, 1995) as a result of Decisions taken at the fourth Meeting of the Parties to the Montreal Protocol held in 1992. The second MBTOC Assessment was presented to Parties in 1998 (MBTOC, 1998), the third in 2002 (MBTOC, 2002), the fourth in 2006 (MBTOC, 2007) and the fifth in 2010 (MBTOC, 2011). The 2014 Assessment Report is MBTOC's sixth.

MBTOC progress reports on advances in alternatives to methyl bromide and other issues related to methyl bromide were included in annual TEAP reports to the Parties (1999; 2000; 2001; 2002; 2003; 2004; 2005 ab; 2006 ab; 2007 ab; 2008 ab; 2009 ab; 2010 ab; 2011 ab; 2012 ab; 2013 ab; 2014 ab). Assessment Reports and TEAP Progress and CUN Reports can be found at http://ozone.unep.org/teap/Reports/MBTOC/index.asp .

Under Decision XXIII/13 (2) taken at the Twenty-Third Meeting of the Parties to the Protocol in 2010, the Parties requested the Assessment Panels to update their 2010 reports in 2014 and submit them to the Secretariat by 31 December 2014 for consideration by the Open-ended Working Group and by the Twenty-Seventh Meeting of the Parties to the Montreal Protocol, in 2015. This MBTOC 2010 Assessment reports provides an update on advances since 2010.

2.5. Definition of an alternative

In this report, following guidance given in Annex 1 of 16 MOP report, MBTOC defined 'alternatives' as:

> *' any practice or treatment that can be used in place of methyl bromide. 'Existing alternatives' are those alternatives in present or past use in some regions. 'Potential alternatives' are those in the process of investigation or development.*
> *MBTOC assumed that an alternative demonstrated in one region of the world would be technically applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex.*

This definition of 'alternatives' is consistent with that used in previous Assessments.

MBTOC is not required in its terms of reference to conduct economic studies on MB and alternatives, however annually it reports on the Parties economic statements on MB and alternatives when requesting CUEs. As per Decision IX/6 and others, alternatives to MB must be technically and economically feasible. Additionally, it was recognised that regulatory requirements, environmental issues and social constraints may make an alternative unavailable in a specific country or region. MBTOC did not omit alternatives from discussion on such grounds in this Assessment report, although MBTOC reports on CUNs do fully consider the availability or lack of availability in specific locations.

2.6. Report structure

In addition to the *Executive Summary* (Chapter1) and this Introductory Chapter (Chapter 2), the assessment report contains the following chapters:

Chapter 3: Methyl bromide production, consumption and progress in phase-out for controlled uses provides statistics on MB production, consumption and major uses from 1991 to the present day, focusing on controlled uses. The chapter has been written in four major parts. The first part provides a brief overview of the major trends, the second part discusses MB production and supply, the third describes consumption in non-Article 5 countries and the fourth describes consumption in Article 5 countries. The two last parts describe the trends in MB fumigant uses by crop or sector.

Chapter 4: Quarantine and Pre-shipment covers MB and alternative treatments for Quarantine and Pre-shipment (QPS) of durable and perishable commodities, including discussion of:

- Production and consumption of MB for QPS purposes
- International (IPPC) standards influencing MB use for quarantine Technical and economic feasibility of alternatives to the main categories of MB use for QPS purposes.
- Constraints to adoption of alternatives

Chapter 5: Alternatives to Methyl Bromide for soil treatment covers a range of alternatives for pre-plant soil fumigation. Discussion includes:

- Commercial alternatives available at a large scale
- Chemical and non chemical alternatives including emerging chemical technologies
- Combined alternatives
- Crop specific strategies
- Adoption of alternatives in Article 5 and non-Article 5 regions

Chapter 6: Structures and Commodities: Methyl Bromide Uses and Alternatives for Pest Control includes discussion on: alternative fumigants such as phosphine and sulfuryl fluoride (including regulatory issues), non-chemical methods such as heat treatment and controlled atmosphere. A section dealing with available alternatives for high moisture dates is also included.

Chapter 7: *Factors assisting the methyl bromide phase-ou in Article 5 countries and remaining challenges* discusses Multilateral Fund (MLF) projects carried out by Article 5 countries that were instrumental in replacing MB in Article 5 Parties. It identifies the main types and objectives of MLF projects, the major technologies being implemented and alternatives adopted on a commercial scale. It discusses lessons learned and barriers to the adoption of alternatives. The chapter outlines other factors that have contributed to MB phase-out, such as voluntary efforts of growers and others undertaken in both Article 5 regions. In view of the phase-out date of 1st January 2015 already in place, it addresses challenges and factors that could potentially put the sustainability of the phase-out at risk.

Chapter 8: Methyl Bromide Emissions discusses:

- Inadvertent and intentional MB emissions.
- Emissions estimated from soil, perishable and durable commodities and structural fumigation treatments.
- Containment techniques.
- Using "best practice" methods to reduce emissions
- Developments in MB recovery and recycling systems.

Chapter 9: Economic Issues Relating to Methyl Bromide Phase-out updates discussion on economic issues influencing adoption of alternatives to MB, in response to Decision Ex.I/4. The chapter outlines the main Decisions of the Parties relating to assessments of the economic feasibility of alternatives in critical use nominations. It covers a significant number of recently published peer- reviewed publications on this topic and identifies the main categories and economic approaches used by different authors to date. It shows that further investigation would be needed to provide a better understanding of the economic impacts of the methyl bromide phase-out, in particular in countries outside of the USA and especially in Article 5 countries.

Appendix 1 contains case studies of adoption of alternatives for preplant (soils) uses of methyl bromide in both Article 5 and non-Article 5 Partes. It also presents one case study based on Japan's strategy to minimise MB use for QPS purposes.

Appendix 2 contains a list of MBTOC members, area of expertise, country of origin and affiliation.

Disclosure of Interest (DOI) statements can be found at the ozone secretariat website and are updated once a year at minimum, or sooner if a members' situation changes in a manner that is relevant to the DOI.

2.7. References

Anon (1994). Methyl bromide annual production and sales for the years 1984–1992, Methyl Bromide Global Coalition Washington, DC

MBTOC (1995). 1994 Report of the Methyl Bromide Technical Options Committee: 1995 Assessment. UNEP: Nairobi. 304pp.

MBTOC (1998). Report of the Methyl Bromide Technical Options Committee. 1998 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi. 374pp.

MBTOC (2002). Report of the Methyl Bromide Technical Options Committee. 2002 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi. 451pp.

MBTOC (2007). Report of the Methyl Bromide Technical Options Committee. 2006 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi. 469pp.

MBTOC (2011). Report of the Methyl Bromide Technical Options Committee. 2010 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi. 400pp.

TEAP (1999). April 1999 Report of the Technology and Economic Assessment Panel. UNEP: Nairobi. 245pp.

TEAP (2000). Report of the Technology and Economic Assessment Panel. April 2000. UNEP: Nairobi. 193pp.

TEAP (2001). Report of the Technology and Economic Assessment Panel. April 2001. UNEP: Nairobi. – 112pp.

TEAP (2002).Report of the Technology and Economic Assessment Panel, April 2002. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme. April 2002

TEAP (2003). Report of the Technology and Economic Assessment Panel, October 2003. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2004). Report of the Technology and Economic Assessment Panel, October 2004. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2005a). Report of the Technology and Economic Assessment Panel, May 2005. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2005b) Report of the Technology and Economic Assessment Panel, October 2005. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2006a). Report of the Technology and Economic Assessment Panel, May, 2006. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2006b). Report of the Technology and Economic Assessment Panel, October, 2006. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2007a). Report of the Technology and Economic Assessment Panel, April, 2007. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2007b). Report of the Technology and Economic Assessment Panel, August, 2007. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2008a). Report of the Technology and Economic Assessment Panel, May 2008. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2008b). Report of the Technology and Economic Assessment Panel, October, 2008. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2009a). Report of the Technology and Economic Assessment Panel, May, 2009. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2009b). Report of the Technology and Economic Assessment Panel, October, 2009. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2009c). QPS Task Force Report. UNEP, Nairobi, Kenya, online: ozone.unep.org, TEAP.org, 332 pp.

TEAP (2010a). Report of the Technology and Economic Assessment Panel, May, 2010. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2010b). Report of the Technology and Economic Assessment Panel, October, 2010. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2010c). May 2010 Progress Report. Vol. 2, Chapter 8: Decision XXI/10 Quarantine and Pre-Shipment Report. UNEP: Nairobi, Kenya, online: ozone.unep.org, 295 pp, 89-158.

TEAP (2011a). Report of the Technology and Economic Assessment Panel, May, 2011. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2010b). Report of the Technology and Economic Assessment Panel, October, 2011. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2012a). Report of the Technology and Economic Assessment Panel, May, 2012. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2012b). Report of the Technology and Economic Assessment Panel, October, 2012. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2013a). Report of the Technology and Economic Assessment Panel, May, 2013. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2013b). Report of the Technology and Economic Assessment Panel, October, 2013. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2014a). Report of the Technology and Economic Assessment Panel, May, 2014. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

TEAP (2014b). Report of the Technology and Economic Assessment Panel. CUN for Methyl Bromide. October, 2014. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi.

3

Chapter 3. Methyl Bromide production, consumption and progress in phase out (controlled uses)

3.1. Introduction

This chapter provides statistics on MB production, consumption and major uses from 1991 to the present day for both non-exempted (controlled) and QPS uses.

The first part of this chapter refer to non-QPS fumigant uses, generally referred to as controlled uses or controlled production/consumption, to distinguish them from other MB uses which presently do not have phase-out schedules under the Protocol, namely QPS and feedstock used in industrial processes. Chapter 4 of this Assessment Report makes reference to exempted or QPS uses, presently more than three times higher than controlled uses.

In the Montreal Protocol, "Calculated levels of production" refer to the amount of controlled substances produced, minus the amount destroyed by technologies approved by the Parties and minus the amount entirely used as feedstock in the manufacture of other chemicals. For methyl bromide, this does not include the amounts used by the Party for quarantine and pre-shipment applications.

Under the Protocol, MB consumption at the national level is defined as ‘production plus imports minus exports, minus QPS, minus feedstock’. It thus represents the national supply of MB for uses controlled by the Protocol (i.e. non-QPS).

Consumption may be different from actual use as MB imported in a particular year for may be consumed in another. Further, stocks of MB already accounted for as consumption may be used in later years. As per Article 7 of the Protocol, Parties are obliged to report production and consumption of MB on a yearly basis (by 30 September of each year). At the time of writing this report, all Parties had reported consumption for 2013 to the Ozone Secretariat, which allows for thorough analysis of consumption trends (Note: two A5 Parties did not report controlled consumption, however their consumption levels have been at zero for more than five years, so it could be assumed that consumption has remained negligible and should not in any way impact results).

3.2. *Methyl Bromide global production and supply for controlled uses*

MB is normally supplied and transported as a liquid in pressurised steel cylinders or cans, since it is a gas at normal atmospheric pressure. Cylinders typically range in capacity from 10 kg to 200 kg, although MB can also be stored in much larger pressurised containers of more than 100 tonnes. In some countries, albeit fewer each year due to health and hazard concerns, MB is still supplied as disposable canisters of approximately 1 lb or 0.454 kg or 1.5 lb (0.75 kg).

3.2.1. Global production for all uses

The information on MB production is compiled from the ODS data reports submitted by Parties under Article 7. All tonnes stated in this chapter are metric tonnes. Table 3-1 below shows the trends in global production, as reported to the Ozone Secretariat by Parties, for all uses, for the years in which data is available (1991 and 1995-2013). (Production per intended use was not discriminated in the early days and it was presented as an aggregate amount).

Trends in the reported production of MB for all *controlled* uses (excluding QPS and feedstock) in all non-article 5 and Article 5 countries are shown in Figure 3-1.

In 2008, a report noted that nearly half of the global anthropogenic emissions of MB in 2005 arose from QPS uses that were not restricted by the Montreal Protocol (Ravishankara *et al*, 2008). The Scientific Assessment Panel report also calculated that if MB production for QPS uses were to cease in 2015, from 2007 to 2050 the total chlorine and bromine in the atmosphere would be reduced by 3.2%. (SAP, 2007; Montzka, 2009). The most recent report from the Scientific Assessment Panel (SAP, 2014) corroborates and further expands this issue. See Chapters 4 and 9 and of this Report on QPS uses and emissions of MB for more detailed information on this topic.

Table 3-2 shows the reported purposes of the total MB that was produced in 2013, compared to the 2009 data in the previous MBTOC Assessment Report. In 2009, essentially equal amounts of MB were produced for use as a fumigant for non-QPS, as for QPS uses. In 2013, however the situation is substantially different, with about 10% of total global production intended for controlled uses (non-QPS fumigant), while 90% was intended for uses that are not controlled under the Protocol.

TABLE 3-1. REPORTED MB PRODUCTION FOR ALL PURPOSES, 1984-2013 (METRIC TONNES).

Year	Fumigant Non-QPS & QPS		Chemical feedstock		Total production [a]	
	MBTOC estimates	Reported by Parties	MBTOC estimates	Reported by Parties	MBTOC estimates	Reported by Parties
1984	41,575		3,997		45,572	
1985	43,766		4,507		48,273	
1986	46,451		4,004		50,455	
1987	52,980		2,710		55,690	
1988	56,806		3,804		60,610	
1989	60,074		2,496		62,570	
1990	62,206		3,693		65,899	
1991	73,602	69,995 [a]	3,610	3,610	77,212	73,605 [a]
1992	72,967		2,658		75,625	
1993	71,157		3,000		74,157	
1994	71,009		3,612		74,621	
1995		65,284		4,754		70,038
1996		67,979		3,104		71,082
1997		69,760		3,829		73,589
1998		70,875		4,448		75,323
1999		61,517		4,453		65,970
2000		56,533		13,132		69,665
2001		45,134		3,190		48,324
2002		40,236		4,331		44,567
2003		36,565		6,759		43,324
2004		35,970		8,012		43,982
2005		32,909		5,014		37,923
2006		29,910		4,475		34,385
2007		25,861		5,224		31.085
2008		19,158		5,097		24,255
2009		20,110		6,408		26,519
2010		19,271		7.019		26,290
2011		13,991		4.699		18,690
2012		12,729		3.910		16,639
2013		12,407		12.459		24,866

a. Total production includes laboratory and analytical uses, but no specific statistics are available on this use.

Sources: data estimates from MBTOC 2002 and 2006 Assessment Reports and Ozone Secretariat data available for 1991 and 1995–2013

TABLE 3-2. REPORTED MB PRODUCTION IN 2013 BY INTENDED PURPOSE

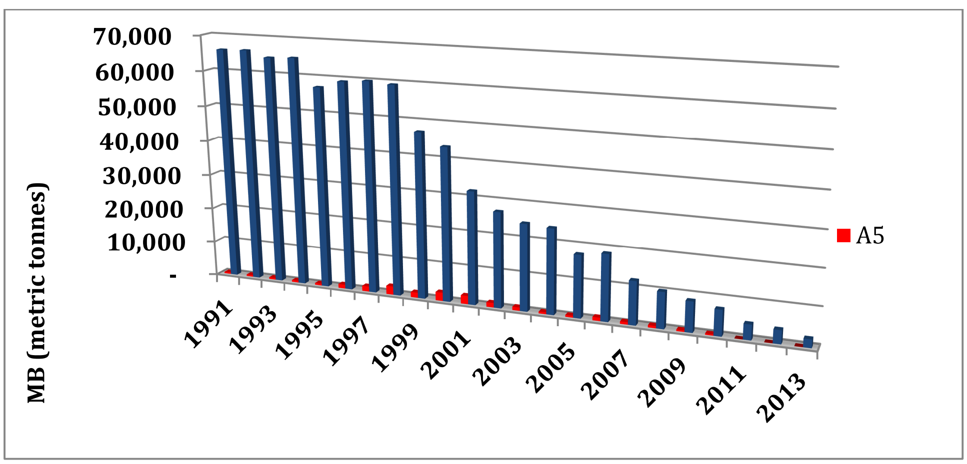
Intended purpose	Reported MB production in 2009		Reported MB production in 2013	
	Metric tonnes	%	Metric tonnes	%
Fumigant non-QPS	11,166	37%	2,493	10%
Sub-total of uses controlled by the MP	**11,166**	**37%**	**2,493**	**10%**
Fumigant for QPS	8,922	37%	9,915	40%
Feedstock	6,408	26%	12.459	50%
Sub-total of uses not controlled by MP	**15,330**	**63%**	**22,374**	**90%**
Total – all uses, controlled and not controlled	**26,506**	**100%**	**24,867**	**100%**

Source: Database of Ozone Secretariat of November 2014.

3.2.2. Global production for controlled uses

Figure 3-1 shows the trend in reported global MB production for all controlled uses from 1991 to 2013 (excluding QPS and feedstock). It illustrates that MB production has occurred primarily in Non-Article 5 Parties, and that global production for controlled uses in 2013 continued the downward trend, totalling 2,493 tonnes or 8.84% of the baseline.

FIGURE 3-1. HISTORICAL TRENDS IN REPORTED GLOBAL MB PRODUCTION* FOR ALL CONTROLLED USES, EXCLUDING QPS AND FEEDSTOCK, 1991 - 2013 (METRIC TONNES)



* Data for 1991 and 1995-2013 were taken from the Ozone Secretariat dataset of December 2013. Data for 1992-94 were estimated from Table 3.1 of the 2002 MBTOC Assessment Report (MBTOC, 2002), Table 3.1 of the 2006 MBTOC Assessment Report (MBTOC, 2007) and Table 1 above.

Non-A5 countries have reduced their MB production for controlled uses from about 66,000 tonnes in 1991 (non-Article 5 baseline) to about 2,326 tonnes in 2013.These figures include production for export to A 5 countries (for Basic Domestic Needs).

A5 countries reduced their MB production for controlled uses from a peak of 2,397 tonnes in 2000 to 167 tonnes in 2013, which represents 13% of their baseline.

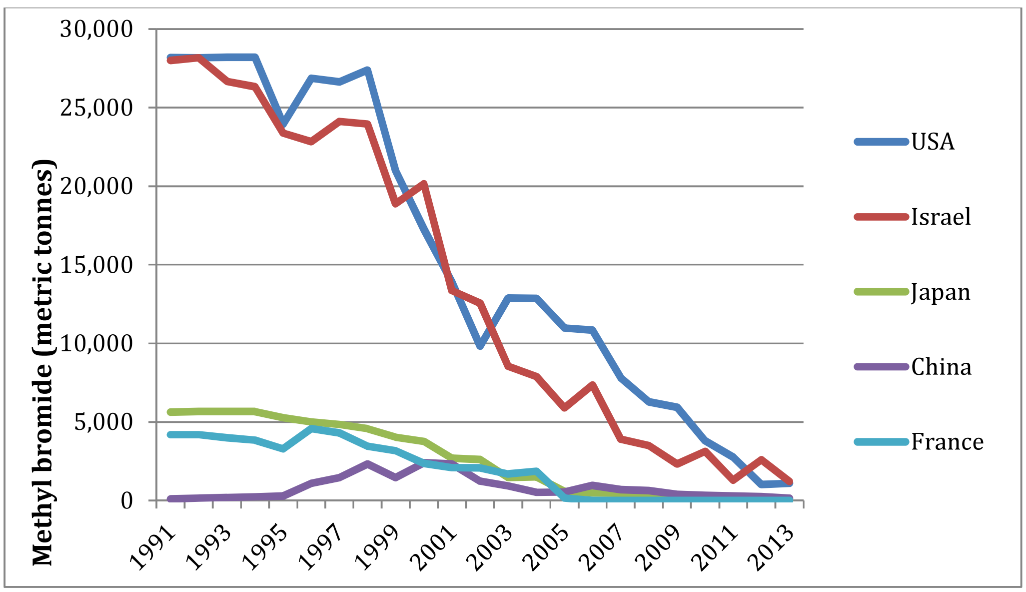
3.2.3. Major producer countries

In 2013 Israel and the USA remained the major producers globally of MB for controlled uses, accounting for 49% (1,218 tonnes) and 45% (1,107 tonnes) respectively, of global production.

Presently, the only A5 Party reporting production of MB is China with 167 metric tonnes in 2013. France, Ukraine and Romania, which produced MB in the past, have now closed down their factories entirely.

Figure 3-2 presents production trends in major MB producing countries for controlled uses for the period 1991 to 2013.

FIGURE. 3-2. GLOBAL MB PRODUCTION TRENDS 1991 – 2013 (CONTROLLED USES)



Source: Ozone Secretariat Database, December 2014

3.2.4. Production facilities

In previous Assessment Reports (MBTC 2002; 2006; 2010), MBTOC has reported on methyl bromide production facilities around the world. In 2000, about 14 facilities in eight countries produced MB for controlled and/or exempted uses, and by 2006 the number had fallen to about 9 facilities in five countries. In 2010, about eight facilities produced MB in five countries.

During the 1990s, six non-A5 countries produced MB (France, Israel, Japan, Romania[1], Ukraine and the US). As reported in the 2010 Assessment, Ukraine ceased production by 2003, while Romania and France ceased production by 2005 and 2006 respectively (MBTOC, 2011; Ozone Secretariat Data Access Centre, December 2014). As a result, the number of non-A5 countries that produce MB fell to three -

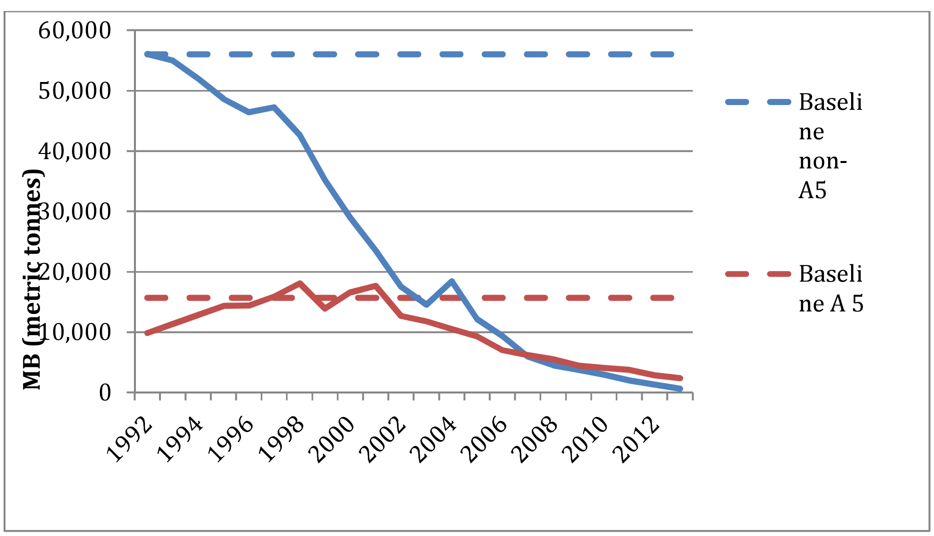
Israel, Japan and US- and these continue to report production as shown in the previous section.

In the past, three A5 countries produced MB (China, India and Korea DPR) but since 2002 only one Article 5 country (China) has officially reported MB production to the Ozone Secretariat. Korea DPR ceased production in 1996, and India was believed to have ceased production in 2003 (Ozone Secretariat Data Access Centre, 2014). However, some companies in India indicate in their websites that they manufacture MB for QPS, non-QPS and/or feedstock uses (e.e. ICRA, 2014). Since 2002, India has not officially reported any MB production under Article 7. For an indicative list of companies producing MB in 2010 please refer to the MBTOC 2010 Assessment Report (MBTOC, 2011).

3.3. Trends in global MB Consumption (and phase-out) for controlled uses

On the basis of Ozone Secretariat data, consumption for controlled uses was estimated to be about 64,420 tonnes in 1991 and remained above 60,000 tonnes until 1998. It was reported to fall to about 8,148 tonnes in 2009, and again to 2,953 tonnes in 2013 as illustrated by Figure 3-3. Consumption in Article 5 Parties was higher than that of non-Article 5 Parties for the first time in 2007. This trend continued up to 2013, when all Article 5 Parties together reported a consumption of 2,342 tonnes (approx. 80% of global consumption for controlled uses) whilst non-Article 5 Parties reported 611 tonnes[1] (approx. 20% of the global consumption).

FIGURE 3-3. BASELINES AND TRENDS IN MB CONSUMPTION IN NON-A 5 AND A 5 REGIONS, 1991 – 2013 (METRIC TONNES)



Source: MBTOC estimates (for early years only) and Ozone Secretariat December 2014.

[1] Consumption for non-A5 Parties was calculated from authorized exempted quantities (critical uses) for non-A5 Parties.

3.3.1. Global consumption by geographical region

An analysis of Ozone Secretariat data revealed that the end of 2013 global consumption of MB for controlled uses was reduced by almost 96% with respect to the global aggregate baseline, as shown in Table 3-3 below. The geographical regions that have made the greatest reductions in consumption in the period 1991-2013 were Europe (100% phase-out), Asia & Pacific and North America (97% reduction). Latin America made the smallest reduction (74%) in this period.

TABLE 3-3. GLOBAL CONSUMPTION OF METHYL BROMIDE BY GEOGRAPHIC REGION, 2013 (METRIC TONNES)

Region	Regional baseline [a]	2013 consumption	% Reduction 1991-2013	Number of Parties
Africa	4,471	340	92%	53
Latin America & Caribbean	6,389	1,637	74%	33
Asia & Pacific [b]	14,657	331	97%	58
Europe [c]	21,472	0	100%	49
North America [d]	25,729	601	97%	2
TOTAL	**72,718**	**2,899**	**96%**	**195**

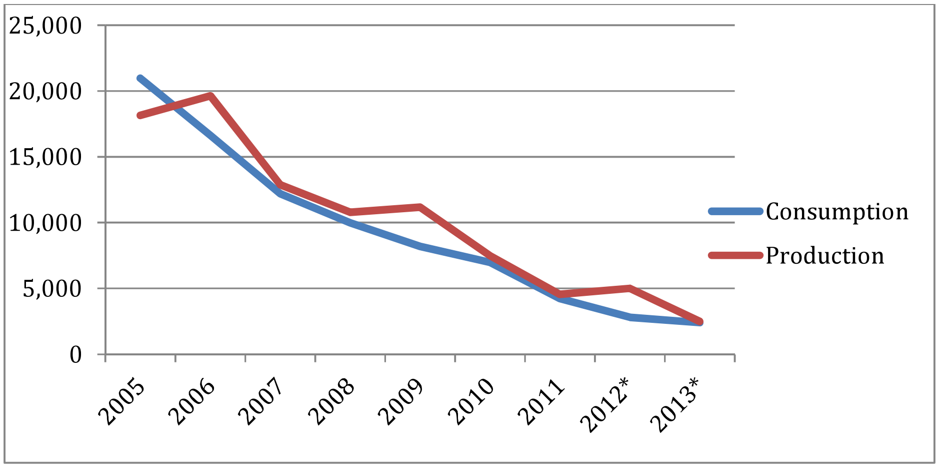
a. Aggregate regional baselines as provided in the database of Ozone Secretariat of November 2014, compiled from 1991 consumption in non-Article 5 countries and 1995-1998 averages in Article 5 countries.
b. The relatively high baseline in this region arises from the historical consumption in Japan and Israel. Asia & Pacific comprises Asian countries (including the middle East), plus Australia and New Zealand
c. The European region comprises the EU, Eastern Europe, Switzerland, Scandinavia and CEIT countries.
d. The North American region comprises US and Canada.
Source: Database of Ozone Secretariat of November 2013.

3.3.2. Production vs. Consumption

When comparing production vs. consumption, it is found that since 2005, a surplus of about 7,760 tonnes of MB produced for controlled uses has accumulated during this nine-year period. This may be due to stocks or to lack of reporting of consumption in some countries or to stocks which have been produced and held for long periods and yet to be consumed. Figure 3-4 illustrates the comparison between global production and consumption of MB for controlled uses between 2005 and 2013 as reported to the Ozone Secretariat.

Please note that the apparent consumption reported by Israel for 2012 (1082 tonnes) and 2013(16 tonnes) is in fact "Production for export to A5 countries for their Basic Domestic Needs (BDN) that did not get exported in the year of production". Therefore the amounts would appear as consumption under Israel, but will be exported in future years. The reported amounts have thus been transferred to the production category since Israel's controlled consumption is presently zero. This information is usually presented in the "Consolidated record of cases of excess production or consumption attributable to stockpiling in accordance with decision XVIII/17 and XXII/20" which is included in the annual data report presented to the MOP.

FIG. 3-4 GLOBAL PRODUCTION VS. GLOBAL CONSUMPTION OF MB FOR CONTROLLED USES 2005 - 2013



Source: Ozone Secretariat Data Access Centre, January 2015

- See comment on Israel reported consumption above.

3.4. Trends in methyl bromide consumption (and phase-out) in Non-Article 5 countries for controlled uses

Figure 3-5 shows the trends in MB consumption in the major Non-A 5 consuming countries for the period between 1991 and 2013. The official baseline for Non-A 5 countries was 56,084 tonnes in 1991 and since then the consumption has declined steadily. Trends in MB consumption in major Non-A 5 regions can be summarised as follows:

- In 1991 the USA, European Union, Israel and Japan used 95% of the MB consumed in Non-Article 5 countries.

- In the past, MB was consumed for controlled uses by 43 out of 48 Non-A 5 countries. Only 3 of these countries continue to use MB, which is being applied under CUEs (Table 3-5).

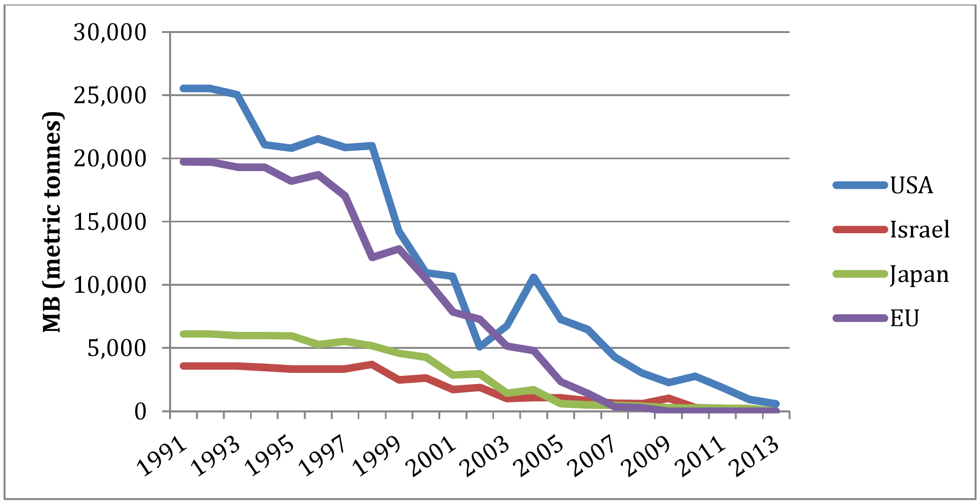
- The US was the highest consumer of MB for much of the period from 1991 to 2013, and its consumption has fluctuated more than that of other countries. US consumption increased after 2002, and then fell to pre-2002 levels in 2007 and to about 1% of its baseline in 2013. Recategorisation of some controlled uses for preplant soil uses in nursery industries to QPS has assisted the US to meet this level. CUEs approved from 2013 onwards have reduced requested amounts significantly, mainly as a result of the registration of additional alternatives. In 2014, the USA submitted a CUN for strawberry fruit – the largest remaining soil pre-plant use – for the last time (for use in 2016).

- Consumption in the EU, the second-highest consumer, showed a steady downward trend since 1999, falling to a low level of authorised consumption in 2008 (under the CUE process) and reaching 0% in 2009. Methyl bromide consumption ceased completely in the EU for both controlled and exempted (QPS) uses in 2010 because MB failed to meet the safety requirements of EU pesticide legislation.

- Japan and Israel have now reached 100% phase-out of MB for controlled uses

An analysis of national MB consumption as a percentage of national baseline in Parties that were granted critical use exemptions (CUE) appears in Table 3-4.

FIGURE 3-5. NATIONAL MB CONSUMPTION IN US, EU, JAPAN AND ISRAEL, 1991 – 2013



Source: Database of Ozone Secretariat in November 2014, reports of the Meetings of the Parties to the Montreal Protocol, and national licensing and authorisation documents relating to consumption. MBTOC estimates for several data gaps in the period 1992 – 1996. (a) Aggregate data for the EU comprising all current member states.

The reported actual consumption is often lower than the authorised CUE tonnage (see Table 3-7). In general, Parties have made significant reductions in MB consumption for CUEs. As noted previously, the EU discontinued submission of CUNs by the end of 2008 and stopped all consumption of MB in 2010.

Japan requested critical uses for the last time in 2011 for use in 2013 and Israel in 2011 for use in 2012. Israel however has reported consumptions of 1082.3 tonnes and 16.2 tonnes for controlled uses respectively in 2012 and 2013.

TABLE 3-4. METHYL BROMIDE CONSUMPTION[A] IN RELATION TO NATIONAL BASELINES IN NON-A 5 PARTIES THAT HAVE BEEN GRANTED CUES

Party	MB consumption [(a)], tonnes (percentage of national baseline)										
	1991 baseline	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013
Australia	704	182 26%	119 17%	55 8%	46 7%	41 6%	33 5%	34 5%	35 5%	33 5%	32 4.4%
Canada	200	58 29%	54 27%	42 21%	38 19%	33 16%	28 14%	34 17%	21 11%	16 8%	13 3.5%
EU	19,735	5,162 26%	2,341 13%	1,410 8%	354 3%	275 1%	0 0%	0 0%	0	0	0 (0%
Israel	3,580	992 28%	1,072 30%	841 23%	638 18%	600 17%	611 17%	291 8%	225 6%	0[c]	0[c] 0%
Japan	6,107	1430 23%	595 10%	489 8%	479 8%	393 6%	279 5%	267 4%	240 4%	220 3.5%	3.3 0.01%
New Zealand	135	21 15%	30 22%	27 20%	7 5%	0 0%	0 0%	0 0%	0	0	0 0%
Switzerland	43	11 24%	4 9%	4 9%	0 0%	0 0%	0 0%	0 0%	0	0	0 0%
United States[d]	25,529	6,755 26%	7,255 28%	6,475 25%	4,302 17%	3,028 12%	2,272 9%c	2,764 11%	1855 7%	923 4%	562 2.2%

Source: Ozone Secretariat database, November 2014.

a. Authorized levels of consumption as authorised by MOP decisions for 2010-2013 which do not always match reported consumption at the Ozone Secretariat for 1991-2009.
b. Baseline of the 27 EU countries that were member states in 2005. The members of the European Union for which the MOP authorised CUEs in 2005/6 were Belgium, France, Germany, Greece, Ireland, Italy, Latvia, Malta, Netherlands, Poland, Portugal, Spain, and the United Kingdom (13 countries). The EU authorised CUEs for 2007 in France, Italy, Netherlands, Poland and Spain (5 countries) and for Poland and Spain for 2008 (2 countries).
c. Israel reported a consumption of 1082.3 tonnes and 16.2 tonnes for controlled uses respectively in 2012 and 2013, even though no CUEs were requested or authorised for these years. This was explained to be "Production for export to A5 countries for their Basic Domestic Needs (BDN) that did not get exported in the year of production". Therefore the amounts would appear as consumption but will be exported in future years.
d. Since 2005, the US has recategorised MB uses for a number of sectors from non-QPS and this has influenced their proportion of consumption against their baseline.

3.4.1. Number of countries consuming MB

About 92% of non-Article 5 countries, i.e. 44 of the total of 48 countries have consumed MB for uses controlled by the Protocol at least on one occasion since 1991. Of these, 86% (38 of 44) no longer consume MB. Consumption data does not include QPS. The member countries of the European Union provide an illustration of the changing patterns of MB use. In the past, 26 of the 27 current countries of the European Community consumed MB for uses controlled by the Protocol. In 2005/6, 13 of these countries still consumed some MB for CUEs. By 2008, only 2 EU countries consumed MB for CUEs, and phase out was completed by the end of 2008 as indicated in Figure 3-7.

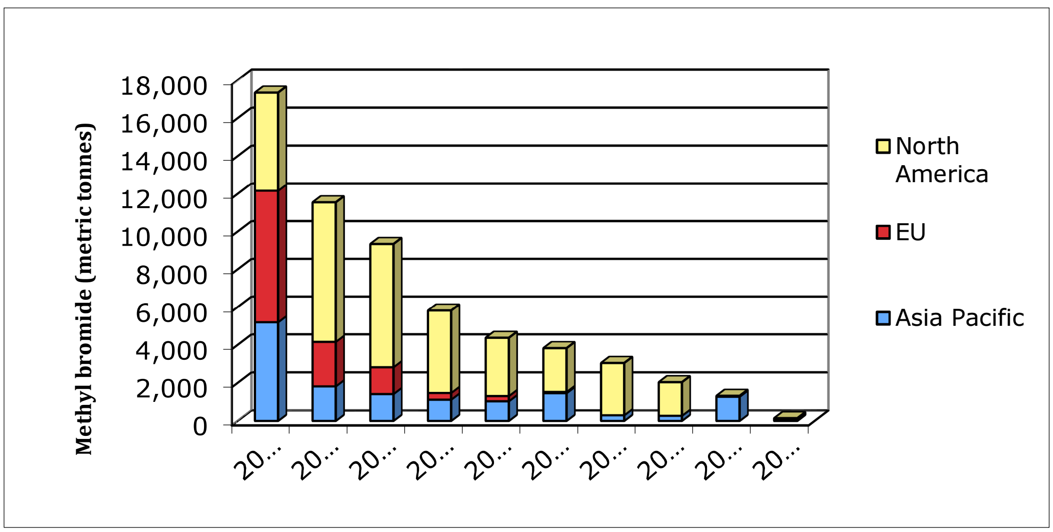
A total of 20 Parties requested CUEs in 2005/6. In 2007 this number fell to 12 Parties, a reduction of 40%, and in 2009 it fell further, to 5 Parties. In 2014, 3 non-A5 Parties requested CUNs (together with 3 A-5 Parties, making use of this provision for the for the first time, in light of the 2015 MB phase-out deadline for this group of Parties).

3.4.2. Consumption by geographical region

The proportions of consumption have changed substantially in non-Article 5 geographical regions since 2002 and particularly since 2006 as the CUE process developed. This is indicated in Figure 3-6 below.

There was a proportional change in consumption to North America (comprising the United States and Canada), which accounted for about 30% (5,181 tonnes) of total non-A5 consumption in 2002, to about 83% (3,269 tonnes) in 2010 (3,954 tonnes) and about 94% of total non-Article 5 authorised consumption in 2013. As mentioned before, authorised consumption is not always in coincidence with reported consumption since Parties may choose to use lesser amounts or draw required amounts from stocks.

FIGURE 3-6. MB CONSUMPTION IN NON-ARTICLE 5 COUNTRIES BY GEOGRAPHIC REGION, AS REPORTED UNDER ARTICLE 7, 2002 - 2013 (METRIC TONNES)



Europe: EU, other non-Article 5 Parties in Europe and non-Article 5 CEITs
Asia: Israel, Japan
Pacific: Australia, New Zealand
Source: Ozone Secretariat database, November 2014
North America: Canada and the United States
Source: Ozone Secretariat Database, January 2015

3.4.3. Trends in nominations for critical use exemptions

This section analyses trends in Critical Use Exemptions in non-Article 5 parties since the inception of the process in 2005. In addition to the quantities authorised for CUE consumption (production + imports), which were described in some sections above, Table 3-5 considers quantities authorised for CUE uses (called 'critical use categories' in MOP Decisions) up to 2014. In addition, some stocks may have been used to support sectors seeking critical use or other sectors. The MOP Decisions on CUEs used in this analysis were Decisions Ex.I/3, XVI/2, Ex.II/1, XVII/9 and XVIII/13.

TABLE 3-5. TREND IN TOTAL TONNAGE OF CUNS AUTHORISED 2005-2014.

Phase in procedure	2005	2008	2009	2010	2011	2012	2013	2014
Nominated amounts submitted to the MOP	18,704.00	8297.739	6244.487	4044.380	2692.366	1460.163	740.533	483.589
Amounts authorised* under the CUE 'use categories' by MOP Decisions	16,050.00	6996.115	5254.933	3572.183	2343.024	1261.304	610.888	483589

Source: Data compiled from TEAP/MBTOC reports, Decisions of MP meetings, national authorisations relating to CUEs, and Accounting Framework reports submitted to the Ozone Secretariat.

3.4.4 Trends for preplant soil uses

In the 2010 round, 27 nominations (CUNs) were submitted for preplant soil uses; of these, 9 were for 2011and 18 for 2012. In the 2014 round and 4 for 2015. Amounts approved by the Parties totaled 230 tonnes for 2011; 1164 t for 2012 and 412 for 2015 (6).

TABLE 3-6. SUMMARY OF MBTOC FINAL RECOMMENDATIONS FOR 2011/2012 AND OF CUNS RECEIVED IN 2013 FOR 2015, BY COUNTRY, FOR PREPLANT SOIL USE OF MB (TONNES)

Country	CUEs Approved Amounts for 2011 to 2016					
	2011	**2012**	**2013**	**2014**	**2015**	**2016**
Australia	**5.950**	29.760	29.760	29.760	29.76	29.76
Canada		5.261	5.261	5.261	5.261	5.261
Israel	224.497		-	-	-	-
Japan	234.396	216.120	-	-	-	-
USA		913.311	461.186	415.067	373.660	231.540
Total	**230.447**	**1164.452**	**496.207**	**450.088**	**408.681**	**266.561**

3.4.5 Trends in postharvest and structure uses

Four Parties submitted eight CUNs for the use of MB in structures and commodities in 2010 for use in 2011 and 2012, while one Party submitted only two in 2013 for use in 2015 and one in 2014 for 2016 as shown in Table 3-7.

TABLE 3-7. POST-HARVEST STRUCTURAL AND COMMODITY CUE 2011 - 2013

Party	Industry	2011	2012	2013	2014	2015	2016
Australia	Rice consumer packs	4.870	3.653	1.187	1.187	-	-
Canada	Flour mills	14.107	11.020	5.044	5.044	-	-
Canada	Pasta manufacturing facilities	2.084	-	-	-	-	-
Japan	Chestnuts	5.350	3.489	3.317	-	-	-
USA	Dried fruit and nuts (walnuts, pistachios, dried fruit and dates and dried beans)	5.000	2.419	0.740	0.740	-	-
USA	Dry commodities/ structures (processed foods, herbs and spices, dried milk and cheese processing facilities) NPMA	17.365	0.2	-	-	-	-
USA	Smokehouse hams (Dry cure pork products) (building and product)	3.730	3.730	3.730	3.730	3.24	3.24
USA	Mills and Processors	135.299	74.510	22.80	22.80	-	-
TOTAL		**187.805**	**99.021**	**33.501**	**33.501**	**3.24**	**3.24**

Source: Critical Use Nominations and MOP Decisions on Critical Use Exemptions

The total MB volume nominated in 2014 for non-QPS post-harvest uses was 3.24 metric tonnes (for dry cure pork), and MBTOC recommended this amount, which was approved by the MOP. In contrast, in 2006, seventeen Parties had submitted CUNs and MBTOC recommended 781.076 tonnes of MB for CUN use for structures and commodities.

3.5 MB consumption trends (and phase-out) in Article 5 Parties for controlled uses

The information about MB consumption in this section has been compiled primarily from the Ozone Secretariat database available in mid January 2015. At the time of making this analysis all Article 5 Parties (except two, but these have reported zero consumption for more than five years) had submitted national consumption data for 2013, which allows for a thorough analysis.

3.5.1. Total consumption and general trends

Figure 3-7 shows the trend in MB consumption in Article 5 countries for the period between 1991 and 2013. Overall trends can be described as follows:

- The Article 5 baseline was 15,867 tonnes (average of 1995-98), rising to a peak consumption of more than 18,125 tonnes in 1998. Article 5 consumption was reduced to 28% of baseline in 2009 (4,435 tonnes) and 14% of baseline in 2013 (2,276 tonnes).

- The vast majority of Article 5 Parties continued to make progress in achieving reductions in MB consumption at a national level, particularly in 2013 (and even further expected in 2014) as the final phase-out deadline of 1st January 2015 grew closer. Trends at the national level can be described as follows:

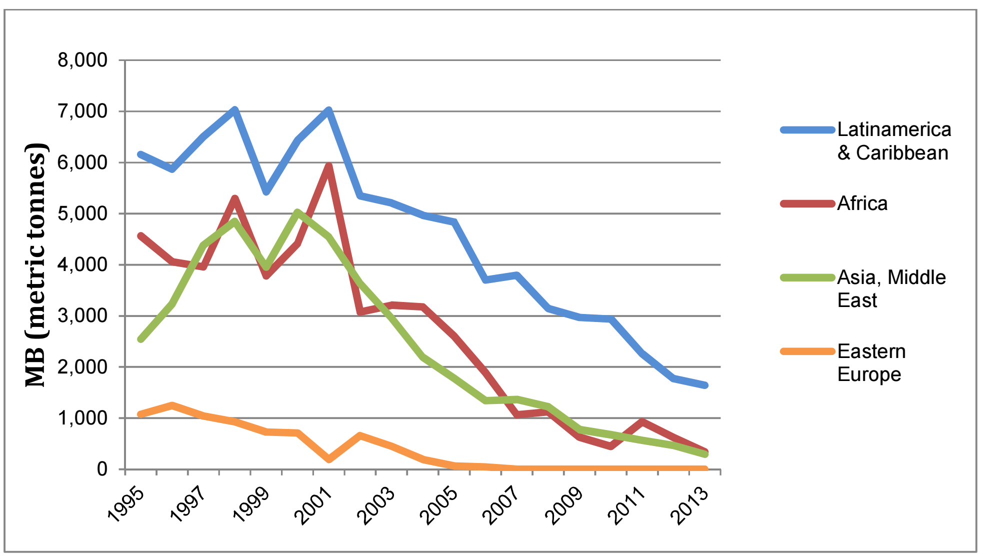
- At the time of preparing this report all Article 5 Parties had reported MB comsumption for 2013 (except Croatia and the Central African Republic but these two countries have reported zero consumption for over ten years), . Only 18 Parties (12%) out of 148 reported MB consumption totalling 2,276 metric tons.

- Seven A5 Parties concentrated almost the total of the remaining MB consumption in 2013. Of this, 72% was located in Latin America and Caribbean, 15% in Africa[2] and 13% in the Asia/ Pacific region.

- Within the top ten consuming A5 Parties in 2013, four concentrate nearly 75% of the remaining controlled consumption in 2013. However, Mexico, the top consumer at 540 metric tonnes in 2013, has already indicated zero consumption in 2014, in compliance with the phase-out schedule agreed with the Executive Committee through the MLF funded project that assisted them in adopting alternatives to MB.

- Three of the of the top consumers have requested CUNs in 2014 for 2015 use: Mexico (for strawberry runners and raspberry nurseries), China (for ginger) and Argentina (for strawberry fruit, tomatoes en peppers).

FIGURE 3- 7. MB REGIONAL CONSUMPTION TRENDS IN ARTICLE 5 COUNTRIES 1991 – 2013



Source: Ozone Secretariat database, 2014

3.5.2. Article 5 national consumption as percentage of national baseline

The great majority of Article 5 countries have achieved considerable MB reductions at national level. With respect to compliance, most Article 5 countries achieved the MP freeze as scheduled in 2002. By 2003, 82% of Article 5 Parties (117 out of 142 Parties) had achieved the 20% reduction step earlier than the scheduled date of 2005,

[2] Corrected consumption figures reported by South Africa to the Ozone Secretariat in 2014 changed these figures with respect to previous MBTOC reports.

as indicated in Table 3-8. All A5 Parties have been in compliance with this step since 2009. For further details see Table 3-11.

TABLE 3-8. STATUS OF COMPLIANCE IN ARTICLE 5 COUNTRIES, 2003 - 2013.

MB consumption as % of national baseline, and status of compliance with 20% reduction step	Number of Article 5 countries			
	2003	2005	2009	2013
MB consumption was 0 - 80% of national baseline	117	136	147	147
MB consumption was more than 80% of national baseline	25	8[a]	0	0
Total	142	144	147	148[3]

Source: Database of Ozone Secretariat in November 2014. For additional details refer to
a. Ecuador, Fiji, Guatemala, Honduras, Libya, Tunisia, Turkmenistan, Uganda.
Source: Database of Ozone Secretariat in November 2014.
[3] South Sudan is reporting under the Protocol since 2012.

3.5.3. Number of Article 5 countries consuming methyl bromide for controlled uses

As in other sections of this chapter, this analysis of MB consumption covers controlled uses only, not exempted QPS uses. Fifty-six Article 5 parties (38%) have never used MB or reported zero MB consumption since 1991. The total number of Article 5 parties that have consumed MB (currently or in the past) is 91, or 62% of the total 148 Article 5 parties. Of the 91 MB-user countries, 73 (80%) have phased out MB, and 18 still reported consumption in 2013.

3.5.4. Small, medium and large Article 5 consumers

Table 3-9 shows the diversity of MB consumption patterns in Article 5 countries. In 2009, 93% of Article 5 countries consumed 0-100 tonnes, 6% consumed 101 – 500 tonnes and <1% (only 1 country) consumed 500 tonnes. In 2013, the number of large consumers (>500 tonnes) decreased from 11 countries in 2001 to 6 countries in 2005, and one country in 2009. No countries remain in this category at present.

TABLE 3-9. NUMBER OF SMALL, MEDIUM AND LARGE VOLUME CONSUMER COUNTRIES, 2009 VS. 2013

MB consumption per country	Number of Article 5 countries	
	2009	2013
0 tonnes	117	130
Small: > 0 – 100 tonnes	20	12
Medium: 101 – 500 tonnes	9	6
Large: > 500 tonnes	1	0
Total number of countries	147	148[3]

Source: Database of Ozone Secretariat in December 2014. [3] South Sudan is reporting as a separate Party to the Protocol since 2012

3.5.5. Major consumer Article 5 Parties

Great progress has been achieved in Article 5 countries that consumed the greatest quantities of MB. In 2009, 8 of these countries still reported consumption between 100 and 500 tonnes while in 2013 only 6 Parties remained in that category (with no Party reporting consumption above 500 tonnes). The top 15 MB consuming countries together accounted for 80% of the Article 5 baseline in the past, and about 86% of total Article 5 consumption in 2000-01. National details are provided in Table 3-10.

TABLE 3-10. FIFTEEN LARGEST ARTICLE 5 CONSUMERS OF MB IN THE PAST, AND PRESENT PROGRESS IN PHASE OUT

Country	National MB consumption (tonnes)			MB eliminated from peak year to 2013	MB eliminated from baseline year in 2013	2013 top consumers
	Peak year [a]	Baseline*	2013			
China	3,501	1,837	167	95%	90%	6º
Morocco	2,702	1,162	0	100%	100%	-
Mexico	2,397	1,885	540	78%	71%	1º
Brazil	1,408	1,186	0	100%	100%	-
Zimbabwe	1,365	928	0	100%	100%	-
Guatemala	1,311	668	400	69%	40%	3º
South Africa	1,265	1,005	234	81%	77%	5º
Turkey	964	800	0	100%	100%	-
Honduras	852	432	0	100%	100%	-
Argentina	841	686	420	50%	39%	2º
Thailand	784	305	0	100%	100%	-
Costa Rica	757	571	0	100%	100%	-
Egypt	720	397	92	87%	77%	7º
Chile	497	354	276	44%	22%	4º
Lebanon	476	394	0	100%	100%	-
Total of former top 15 countries	19,840	12,610	2,129	89% average	83% average	-

[a] Maximum level of national MB consumption in the past. * 1995-1998 average
Ozone Secretariat Database January 2015.

The top 15 countries reduced MB consumption by 83% from 1995-98 baseline on average. By 2013 these large consumers phased out 89% of their historical peak use of MB. Notably, several have phased-out completely, in advance of the 2015 deadline, for example Brazil, Morocco, Turkey, Zimbabwe, Lebanon and Costa Rica.

3.5.6. Assessment of progress in phase-out in Article 5 countries

The trends and indicators analysed above lead to the conclusion that Article 5 countries have achieved significant progress in reducing and phasing out MB, as illustrated by the following summary of the situation in 2013:

- Many Article 5 countries have implemented MLF projects and other activities that have led to MB reductions and phase out;

- Article 5 countries reduced their production for controlled uses from a peak of 2,397 tonnes in 2000 to 167 tonnes in 2013, which represents 13% of their baseline.
- Only 18 countries from a list of 148 are still using MB in 2013.
- Latin America with 71% of the remaining MB consumption is the slowest region in reducing its use: Mexico, Argentina, Guatemala and Chile were the world's top 4 MB consumers for controlled uses in 2013.
- Large consumption (>500 tonnes) remains in only one Article 5 country. Other 6 countries remain medium consumers (101-500 tonnes), while 12 are small ones (<100 tonnes).

3.6 Methyl Bromide use by sector – Controlled uses

3.6.1. Where Methyl Bromide was historically used

Since the beginning of the MB phase-out process some key sectors using this fumigant and which clearly needed alternatives became apparent. Sectors such as tomatoes, strawberries, peppers, eggplants, cucurbits, flowers and stored grain of different kinds were particularly impacted by the MB phase-out in some countries. The tobacco industry in general, used large amounts of MB for seedling production. In many countries, structures such as mills and warehouses were often disinfested with MB fumigation.

Soil uses were traditionally much larger than uses for postharvest and structures (about 90% vs. 10% of total consumption) but technically and economically feasible alternatives were equally important for both sectors.

Table 3-11 describes historic uses of MB for both controlled and exempted uses. The following sections provide an analysis of present, remaining uses of MB (as at 2013).

TABLE 3-11. HISTORIC USES OF METHYL BROMIDE WORLDWIDE

In soil:	• As a preplant treatment to control soil borne pests (nematodes, fungi and insects) and weeds of high-value crops such as cut flowers, tomatoes, strawberry fruit, cucurbits (melon, cucumber, squash), peppers and eggplant.
	• As a treatment to control 'replant disease' in some vines, deciduous fruit trees or nut trees;
	• As a treatment of seed beds principally against fungi for production of a wide range of seedlings, notably tobacco and some vegetables;
	• As a treatment to control soilborne pests in the production of pest-free propagation stock, e.g. strawberry runners, nursery propagation materials, which in some cases need to meet certification requirements;
In durables:	• As a treatment to control quarantine pests in import-export commodities or restrict damage caused by cosmopolitan insect pests in stored products such as cereal grains, dried fruit, nuts, cocoa beans, coffee beans, dried herbs, spices, also cultural artefacts and museum items;
	• As an import-export treatment to control quarantine pests and in some cases fungal pests in durable commodities such as logs, timber and wooden pallets, artefacts and other products;
In perishables:	• As an import-export treatment to control quarantine insects, other pests and mites in some types of fresh fruit, vegetables, tubers and cut flowers in export or import trade;
In "semi-perishables"	• As a treatment to control cosmopolitan or quarantine insects, to prevent fermentation or inhibit sprouting and fungal development in products that have high (>25% wb) or very high (>90%) moisture contents, for example high moisture dates and fresh chestnuts, and also some stored vegetables, e.g. yams, and ginger;
In structures and transport:	• As a treatment to control insects and rodents in flour mills, pasta mills, food processing facilities and other buildings;
	• As a treatment to control cosmopolitan or quarantine insect pest and rodents in ships and freight containers, either empty or containing durable cargo.

Source: MBTOC 2006 Assessment Report

3.6.2. Present MB applications (controlled uses in 2013)

The data reported in this section was compiled from several sources. MBTOC estimated the relative proportion of MB use in the soil and postharvest sectors in non-Article 5 countries by examining CUEs that have been authorised by the MOP Decisions and, where available, by national authorisation or licensing procedures.

Further, MBTOC carried out a survey amongst Article 5 ozone offices in about fifteen key countries that reported consumption larger than 5 metric tonnes of MB in 2012. 'The survey was also sent to countries reporting use higher than 50 tonnes of MB for QPS purposes and results of this analysis can be found in Chapter 6 of the Assessment Report. The survey sample covered over 90% of the A5 MB consumption for non-QPS purposes in 2013.

Most A 5 countries are implementing or have completed MLF projects and therefore keep updated information on MB use categories. As a result the quality of information on MB uses in A 5 countries is now more reliable than the past. However, some countries were able to provide only estimates rather than national survey data, and some countries did not submit a reply, so the MBTOC survey results in this chapter should be regarded as estimates rather than precise data. MBTOC also contacted UNEP-DTIE CAP offices in the three Article 5 regions where these operate (Latin America, Asia/ Pacific and Africa), national experts and NOU's and implementing agencies and is very grateful for the valuable information and help provided. Results from the survey and other sources mentioned above were used for the preparation of the following graphs.

3.6.3. Global overview of fumigant uses

MB has been used commercially as a fumigant since the 1930's (MBGC, 1994). It is a highly versatile product, used in many different applications. MB is mainly used for the control of soilborne pests (such as nematodes, fungi, weeds, insects) in high-value crops, and to a lesser extent for the control of insects, rodents and other pests in structures, transport and commodities. These categories of use can also be divided into two major groups:

- Quarantine and pre-shipment (QPS) uses, which were estimated to account for about 77% of total MB fumigant use in 2013 (as controlled uses are phased out, QPS use has become proportionally higher; it was reported at about 38% of total uses in 2005). These uses are not subject to Protocol reduction schedules. QPS uses include wooden pallets, durable commodities in the import/export trade, transport and some perishable commodities. Detailed information on QPS is provided in Chapter 4 of this Assessment Report.

- Non-QPS uses, which were estimated to account for approximately 23% of MB fumigant usage in 2013. These uses are controlled under the Protocol and as such are subject to phase-out schedules. Non-QPS uses include soil fumigation, structures (mills and food processing) durable stored products, semi-perishables and some transport.

Data on production and consumption of MB for QPS purposes is now much more accurate than in the past, since reported information was made public after the 20th MOP (Dec XX/6). The non-QPS tonnage was calculated on the basis of the tonnage of CUE uses authorised by the MOP and by parties during the licensing phase for non- Article 5 Parties and the results of the MBTOC survey of MB uses in Article 5 countries. Amounts used for QPS purposes are those reported by Parties and posted at the Ozone Secretariat website. Using this data, MBTOC estimated that approximately 77% of global use was for QPS (9.827 tonnes), while approximately 23% was used for non-QPS (2,882 tonnes). The latter comprised an estimated 94% for soil fumigation and about 6% for postharvest (durable commodities and structures) as indicated in Table 3-12.

TABLE 3-12. ESTIMATED USE OF MB FOR QPS AND NON-QPS IN 2005 AND 2013

Major sectors	Reported MB use in 2005 (mt)	% of total	Reported use in 2013	% of total
QPS	10,825	34%	9.827	77%
Non-QPS comprising:-	20,968	66%	2,882	23%
Soil			2,698	93%
Commodities			179	7%
Structures			5	0%
Total QPS & non-QPS	**31,793**	**100%**	**12,709**	**100%**

Sources: Reported MB production for QPS in database of Ozone Secretariat of December 2014, CUE uses authorised by MOP Decisions and by parties during licensing, and MBTOC survey of MB uses for controlled and exempted uses in Article 5 countries carried out in 2014.

3.6.3.1. Quarantine and pre-shipment

In 2013 the reported MB production for QPS was 9,915 tonnes. This represented about 80% of total global MB production for all purposes. Consumption for QPS uses was 9,827 tonnes. Detailed discussion on production, consumption and use of MB for QPS purposes can be found in Chapter 6 of this Assessment Report.

3.6.3.2. Non-QPS sectors

MBTOC has estimated that the total non-QPS use can currently be allocated to major sectors as follows: approximately 93% for soil fumigation, about 6% for commodities and less than 1% for structures in 2013. In non-Article 5 countries the estimated proportions in 2013 were approximately 92% for soil uses, about 8% for structures and durables. The results of the MBTOC survey indicated that Article 5 countries in 2013 used approximately 94% of MB for soil fumigation, and 6% for structures and durable commodities.

3.6.4. Non-QPS uses in non-Article 5 countries

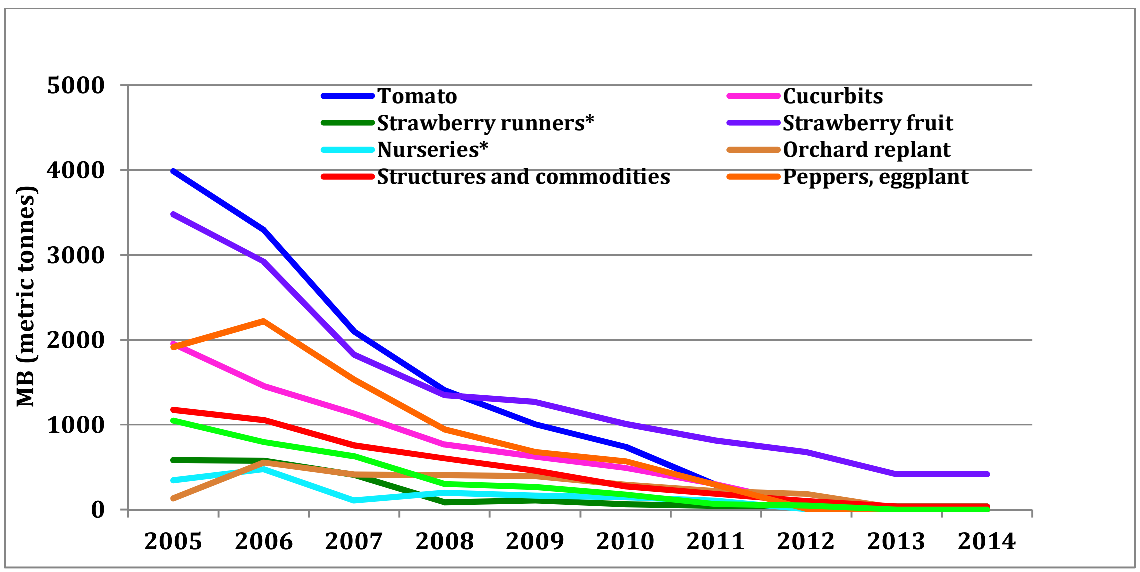
The remaining controlled uses of MB in non-Article 5 countries are allowed since 2005 as critical use exemptions only, and this has been fully followed by all non-A5 Parties. However, in 2011, Kazakhstan ratified the Protocol's Copenhagen Amendment and thus came into non-compliance with methyl bromide obligations, with a reported consumption of 10 tonnes of MB in 2011 and 32 tonnes in 2013. At the 26th MOP of November 2014, Kazakhstan presented a plan t return to compliance now contained in Decision XXVI/13, whereby they will cease all production for controlled uses by 1st January 2015 (except under the critical exemption process, should they find it necessary to apply).

CUEs have been authorised by the Meetings of the Parties for the following crops in specific circumstances: tomatoes, strawberry fruit, peppers, eggplant, cucurbits, ornamentals (cut flowers and bulbs), orchard replant, nurseries, strawberry runners, and several miscellaneous crops.

The postharvest uses of MB comprise specific circumstances in food processing structures such as flour mills, pasta mills, durable commodities such as dried fruits, nuts, rice, and other products such as cheese in storage, cured pork products in storage and fresh market chestnuts.

Figure 3-8 illustrates the trends in the CUE tonnage authorised by MOP Decisions for individual major crops and postharvest uses, from 2005 to 2014. Some parties made further reductions in the CUE tonnages during the licensing procedures, but these reductions are not taken into account in Figure 7. Substantial reductions in the MOP-authorised tonnage can be seen for all crops since 2005, and in fact complete phase-out has been achieved in most crops. The USA has indicated that 2014 was the last year of submission of a CUN for strawberry fruit (for use in 2016). This leaves strawberry runners as the sole soil sector for which CUN are being requested by non-A5 Parties at present.

FIGURE 3-8. MAJOR USES OF MB CUEs AUTHORISED BY MOP FOR NON-ARTICLE 5 PARTIES, 2005–2014.



* The USA classifies MB uses for nurseries (including strawberry runners) as QPS and are not accounted for here

Source: Authorised lists of CUEs in Decisions published in the reports of the meetings of the Parties to the Montreal Protocol 2004-2014.

The chart indicates metric tonnes authorised for CUEs by MOP Decisions. Some parties made further tonnage reductions (not shown in this chart) during the licensing procedures.

3.6.5. Major soil uses in non-Article 5 countries

This section examines the trends in the soil uses for major crops in the period 2005-2011. In Figure 8, the left-hand chart shows the quantity of MB authorised by MOP Decisions for strawberry fruit CUEs in individual parties. (Some parties made further reductions in CUEs at the licensing phase but these reductions are not shown in the Figure above). The number of countries using CUEs for strawberry fruit was 8 in 2005, 2 in 2010 (Israel and US) and only one since 2011 (USA). The total CUE tonnage authorised by MOP Decisions for strawberry fruit was reduced by over 90% since 2005. Additional reductions were also made at national level during the licensing phase, but are not shown in these graphs. The USA has indicated that 2014 was the last year they have requested a CUE for strawberry fruit (for use in 2015)

The total CUE tonnage initially authorised for tomatoes by the MOP in 2005 has now been completely replaced. The number of countries that received CUEs for tomato was 5 in 2005, and 2 in 2010 (Israel and USA). Nominations for this use from non-A5 Parties ceased completely in 2010. As indicated in Fig. 3-8 above, other key sectors included cucurbits, peppers and eggplant, ornamentals (cut flowers and bulbs) and orchard replant. All of these sectors have now fully transitioned to alternatives in non-A5 Parties.

3.6.6. Structures and commodities uses in non-Article 5 countries

Postharvest uses can be divided into structures and commodities. Structures comprised more nearly 70%of the postharvest CUE tonnage authorised in 2013, but requests for critical uses in structures have now stopped completely. The only postharvest use remaining at present is for cure ham in the USA. See section 3.4.5 and table 3-7.

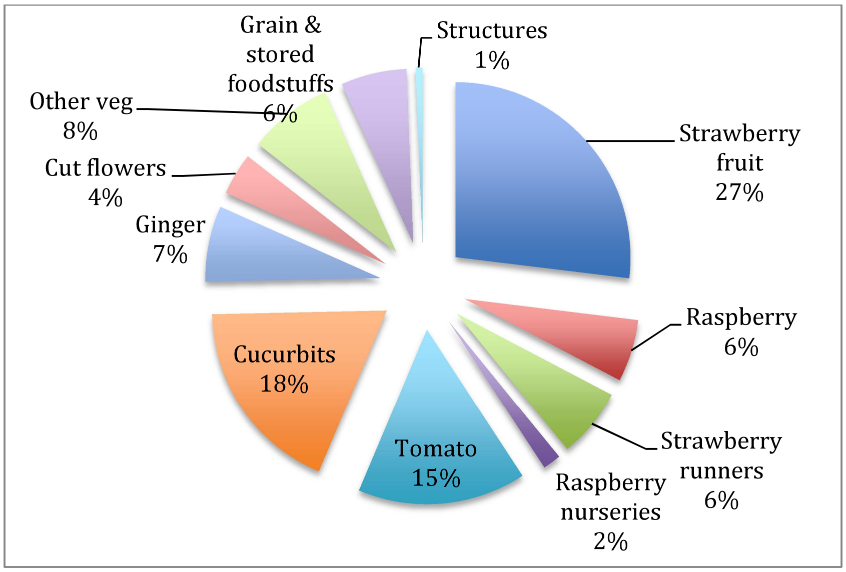
3.6.7. Major controlled uses in Article 5 countries

This section provides an overview of major controlled (non-QPS) uses in Article 5 countries. The recent MBTOC survey carried out in 2014, identified the major MB uses in 2013 as follows: approximately 94% was used for soil fumigation (i.e. for treatment of soil before planting crops), approximately 6% for durable commodities and less than 1% for structures (excluding QPS). These survey results should be regarded as estimates rather than precise data. Percentage variations between results obtained in 2005, 2009 and 2013 are not directly comparable, since in that period large MB users have phased out completely and others have significantly reduced consumption. This may result in sectors that were small in the past now occupying a larger proportion of the total.

Figure 3-12 presents the survey results for A5 countries, indicating that the major crops/ sectors using MB in 2013 were cucurbits (i.e. melon, cucumber and similar crops) (18%), tomatoes (15%) strawberry fruit and other berries (raspberries, blueberries, blackberries; this use particularly reported in Mexico) (33% combined), cut flowers (4%) ginger (7%), strawberry runners and raspberry nurseries (8% combined), and other vegetables 8% (peppers, eggplant, green beans and others). About 7% of the MB used was allocated to the postharvest sector, 6% to grain and stored foodstuffs and about 1% to structures (flour mills).

Chapters 5 and 6 of this Assessment Report contain information on alternatives to MB for these key sectors. Further detailed information can also be found in previous MBTOC Assessment Reports of 2010, 2006 and 2002.

FIGURE 3-12. MB USE SURVEY RESULTS: MAJOR CROPS USING MB IN ARTICLE 5 COUNTRIES IN 2009.



Source: MBTOC survey of MB uses for controlled purposes (via the Ozone Secretariat) and MBTOC estimates

3.6.8. Critical Use Nominations from Article 5 Parties

With the 2015 deadline for complete phase-out of controlled uses of MB now in force for Article-5 Parties, nominations for critical uses have now been submitted for some sectors as shown in Table 3-13. As noted in previous sections, critical use nominations have been submitted in the past by non-Article 5 Parties in all of these sectors.

TABLE 3-13. CUNS (TONNES) SUBMITTED BY ARTICL-E5 PARTIES IN 2014 AND 2015 FOR 2015 AND 2016 (FIGURES IN METRIC TONNES)

Country	Sector	CUN Request for 2015 or	CUE Approved for 2015	CUN Request for 2016 *
Argentina	Strawberry fruit	110.0	64.30	77.0
	Tomato	145.0	70.0	100.0
China	Ginger (Field)	90.0	90.0	90.0
	Ginger (Protected)	30.0	24.0	24.0
Mexico	Raspberry nurseries	70.0	43.539	56.018
	Strawberry nurseries	70.0	41.418	64.960
South Africa	Commodities	-	-	70.0

* To be decided at 27th MOP, November 2015

3.7. References

ICRA (2014). Intech Pharma Private Ltd. Accessed January 2015. http://www.icra.in/Files/Reports/Rationale/Intech%20Pharma_r_07102014.pdf

MBTOC (2011) Methyl Bromide Technical Options Committee 2010 Assessment Report. UNEP, Nairobi, 424 pp.

Montzka, S. (2009) The influence of methyl bromide from QPS applications on the ozone layer. Presentation on Scientific Assessment Panel report. Workshop on methyl bromide use for quarantine and pre-shipment purposes, 3 November 2009, MoP-21, Port Ghalib.

Ozone Secretariat (2014) Data Access Centre database of ODS data reported by Parties to the Montreal Protocol under Article 7, website accessed November 2014.

Ravishankara, A.R, Kurylo, M.J, and Ennis, C.A (eds.) (2008) Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure. Synthesis and Assessment Product 2.4. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Compiled under the auspices of the National Research Council (NRC) and National Science and Technology Council. November 2008. Department of Commerce, NOAA's National Climatic Data Center, Asheville, NC, p.22, 44, 53.

SAP (2007) Scientific Assessment of Ozone Depletion: 2006. World Meteorological Organisation, Geneva. p.8.3 and 8.29.

SAP (2014). Scientific Assessment of Ozone Depletion. UNEP, Nairobi http://ozone.unep.org/Assessment_Panels/SAP/Scientific_Assessment_2014/Scientific_Assessment_Report_2014.pdf

4

Chapter 4. Alternatives to methyl bromide for Quarantine and Pre-shipment applications

4.1. Introduction

Quarantine and pre-shipment (QPS) treatments with methyl bromide (MB) are used to kill pests on perishable and durable commodities listed as quarantine pests (quarantine); on durable and perishable commodities or in trade to render them "practically free" of noxious pests and other organisms (pre-shipment), QPS treatments are also used on soils, and in structures and commodities to eliminate or control exotic organisms of quarantine significance. Periodic QPS uses of MB have been made within countries to try and prevent spread of pests, when an exotic pest is found in a new region. Since 2003, some countries have interpreted that treatment to avoid movement of soil pests within a country on propagation material may also qualify for QPS MB use.

QPS treatments with methyl bromide (MB) are generally applied to commodities in trade between countries and between quarantine regions inside a country. *Perishable commodities* include fresh fruit and vegetables, cut flowers, ornamental plants, fresh root crops and bulbs. *Durable commodities* are those with low moisture content that, in the absence of pest attack, can be safely stored for long periods and include foods such as grains, dried fruits and beverage crops and non-foods such as cotton, wood products and tobacco and other non-agricultural goods that may harbour quarantine pests such as tyres, household goods, and industrial goods.

The production and consumption of methyl bromide (MB) for QPS is exempted from the control measures (phaseout) agreed under Article 2H para 6 of the Montreal Protocol. Since the MBTOC 2010 Assessment Report, MBTOC has continued providing detailed information on alternatives to MB for QPS uses through the TEAP Progress Reports as well as responses to Decisions from the MOP (i.e. Decisions XXIII/5 and XXIV/15, see Table 4-1), following previous work reported in detail in the MBTOC 2010 Assessment Report (see MBTOC, 2011, chapter 6).

Development of methyl bromide alternatives for Quarantine applications on commodities continues to be a difficult process, exacerbated by the multitude of commodities being treated, the diverse situations where treatments are applied, a constantly changing trade and regulatory landscape, requirements for bilateral agreement on QPS measures, requirement for very high levels of proven effectiveness, often for several different target species, lack of patent coverage or other commercial protection for some potential alternatives, and the low price and plentiful supply of methyl bromide for QPS purposes. Regulations favouring methyl bromide treatment or prescribing methyl bromide alone are a major barrier to adoption of alternatives as often there is little incentive for the regulation to be changed.

4.2. Reasons for QPS uses of methyl bromide

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

Most current uses of MB on durables and perishable commodities worldwide are highly specialised. MB use has been in routine use for decades as a well-developed system with a good record of successful use. Some examples of current QPS uses include:

- Fumigation of cut flowers found to be infested on arrival in the importing country with quarantine pests (quarantine treatment)
- Fumigation of fruit before export to meet the official phytosanitary requirements of the importing country for mandatory fumigation of an officially-listed quarantine pest (quarantine treatment)
- Fumigation of grain before export to meet the importing country's existing import regulations that require fumigation of all export grain consignments (pre-shipment treatment)
- Fumigation of log exports either prior to shipment or on arrival against official quarantine pests.

Further examples of treatments that may be QPS have been provided in previous reports.
Requirements for MB alternatives are often compared with MB's properties which include such desirable features as:

- Rapid speed of treatment. This is particularly useful for perishable products that must be marketed rapidly;
- Low cost for fumigation;
- Relatively non-corrosive and applied easily to shipping fumigation facilities, containers or to bagged, palletised or bulk commodities 'under sheets';
- A long history of recognition as a suitable treatment by quarantine authorities;
- Broad registration for use;
- Good ability to penetrate into the commodity where pests might be located; and
- Rapid release of gas from the commodity after exposure

MB also has a number of undesirable features including:

- A high level of toxicity to humans;

- Odourless, making it difficult to detect;
- A significant ozone depleting potential;
- Adverse effects on some commodities, particularly loss of viability, quality reduction, reduced shelf life and taint;
- Slow desorption from some commodities and at low temperatures, leading to hazardous concentrations of MB in storage and transport subsequent to fumigation; and
- Excessive bromide residues retained in the product.

In certain situations, MB is the only treatment approved by national quarantine authorities for QPS applications for international trade. Quarantine treatments are supported by extensive scientific data documenting the responses of pests to MB to verify a high level of treatment efficacy for pests that are considered to be serious threats to the importing country. Intracountry quarantines are aimed at curtailing the spread, containing or eradicating spread of quarantine pests that may be established in a restricted area or region of that country. In some cases, production of propagation material of certified high plant health status is considered a quarantine activity. Pre-shipment treatments are aimed at ensuring that products in international trade meet set standards of lack of pests.

4.3. Definitions of Quarantine and Pre-shipment

4.3.1. Origin and original intent of the QPS exemption

At the 1992 Meeting of the Parties in Copenhagen that established methyl bromide as a controlled Ozone Depleting Substance, Article 2H of the Protocol specifically excluded QPS from control measures when it stated, *inter alia*:

> *'The calculated levels of consumption and production …shall not include the amounts used by the Party for quarantine and pre-shipment applications'*

This was the first time that QPS was mentioned in the Protocol documentation. Definition of 'quarantine' and 'pre-shipment' was deferred to a later meeting.

At the time that Article 2H was agreed in Copenhagen in 1992, the Parties understood that there were no alternatives to MB for a diverse range of treatments carried out with MB for QPS. The Parties recognised that although QPS consumption was about 10% of global MB consumption at the time, this volume was nevertheless very significant in allowing inter- and intra-country trade in commodities *in the absence of site-specific alternatives*.

Unless site specific alternatives to MB were available for QPS that were tested and approved in both A 5 and non-A 5 countries, there was a strong likelihood of disruption to international trade if the exemption for QPS were not available.

Invasions by new pest species into a country or region can have serious adverse effects economically and on agricultural production and natural resources. The combined economic costs of new pests may be significant, with implications for environmental policy and resource management; yet full economic impact assessments are rare at a national scale.

The containment and eradication of a newly discovered pest is generally difficult, often highly controversial, and frequently requires substantial resources costing millions of dollars and the commitment of all involved, however there are many examples of successful eradication campaigns (MBTOC, 2011). Methyl bromide treatment is considered an important tool for some eradication and containment attempts. It was successfully used in the eradication of khapra beetle from both western USA in the 1950s and more recently from Perth, Western Australia (Emery *et al.,* 2010). It was recently being used as a soil fumigant to contain and possibly eradicate the exotic nematodes *Globodera pallida* and *R. rostochiensis* in parts of USA (TEAP, 2009).

4.3.2. 'Quarantine' and 'Pre-shipment'

The scope of the QPS exemption set out in Article 2H paragraph 6 has been clarified in Decisions VII/5 and XI/12 of the Protocol relating to the terms 'Quarantine' and 'Pre-shipment'. TEAP (2002) has provided some discussion and examples of cases that might or might not fall within the QPS exemption. There is also discussion of the scope of the exemption from control under the Protocol for QPS uses of methyl bromide in TEAP (1999) and the UNEP/IPPC (2008) publication 'Methyl Bromide: Quarantine and Pre-shipment Uses'. Differences in interpretation of the scope and application of the QPS exemption by individual Parties have led to some differences in the uses that were reported as QPS in the data accessed by MBTOC.

Specifically, the Seventh Meeting of the Parties decided in Decision VII/5 that:

a) *"Quarantine applications",* with respect to methyl bromide, are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where:

   i. *Official control is that performed by, or authorised by, a national plant, animal or environmental protection or health authority;*
   ii. *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*

b) *"Pre-shipment applications"* are those treatments applied directly preceding and in relation to export, to meet the phytosanitary or sanitary requirements of the importing country or existing phytosanitary or sanitary requirements of the exporting country;

The definition of 'Pre-shipment' is unique to the Montreal Protocol. It is given and elaborated in Decisions VII/5 and XI/12. The Eleventh Meeting of the Parties decided in Decision 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"*.

As per decision VII/5, official requirements are those, which are "performed by, or authorised by a national plant, animal, environmental, health or stored product authority".

The definition of a quarantine pest under the Montreal Protocol differs from that under the IPPC (International Plant Protection Convention) by one word, ‘economic’: the Montreal Protocol refers to *“pests of potential importance”* while the Convention definition refers to “*pests of potential economic importance”*. However, under the IPPC, it has been clarified in a supplement to ISPM No. 5 that ‘economic’ includes the effect of changes (e.g. in biodiversity, ecosystems, managed resources or natural resources) on human welfare.

The IPPC deals with pests of plants, and not of livestock, which would have potential economic impact, again including environmental considerations. The scope of the IPPC is analysed in further detail in MBTOC and TEAP reports (MBTOC, 2011, TEAP, 2010). Its definition of a quarantine pest relates to official control, specifically pests of propagation material and seeds for planting, and do not include pests that affect quality in storage.

The Montreal Protocol’s definition covers environmental and other pests that might endanger a region without direct quantifiable economic loss. An interpretation of Decision VII/7 is that the use of methyl bromide as a quarantine treatment may only be for pests that are officially recognised as quarantine pests and must be officially authorised by a competent authority.

QPS treatments under the Montreal Protocol relate not only to official phytosanitary treatments, but may also apply to ‘sanitary’ treatments, e.g., against human or animal pathogens and vectors (e.g. mosquitoes), covered by International Agreements (IAs, multilateral agreements) such as the World Animal Health Organisation (OIE) and World Health Organization (WHO).

Pre-shipment treatments target non-quarantine pests that may be present in both the exporting and importing country. These pests are usually ones that affect storage or end-use quality of the exported commodities, and are outside the direct scope of the IPPC. However, the model Phytosanitary certificate from Guidelines for Phytosanitary Certificates provided in ISPM 12 contains the following optional clause: “They are deemed to be practically free from other pests.” This relates to Pre-shipment uses where a certification is needed to meet commodity shipping requirements.

As a result of the broad coverage of the Montreal Protocol QPS concept, the actual QPS uses are covered by several different International Agreements and domestic regulatory bodies.

4.4. Decisions relating to QPS use of methyl bromide

Since 1992, there have been various Decisions taken by the Parties to the Montreal Protocol related to this QPS exemption. These have concerned definitions and clarification of definitions, and have also requested TEAP to conduct closer evaluations of MB uses for QPS purposes and their possible alternatives or opportunities for reducing emissions. TEAP has responded to these Decisions through its MBTOC as well as appointing special task forces.

Table 4-1 below lists decisions relating to QPS uses of MB and summarises the main issues comprised by each. Reports prepared in response to such Decisions – when requested by the Parties – can be found at the Ozone Secretariat website.

TABLE 4-1: SUMMARY OF DECISIONS RELATING TO QPS USES OF METHYL BROMIDE

Decision No.	Decision title	Summary
VI/11(c)	Clarification of «quarantine» and «pre-shipment» applications for control of methyl bromide	Gives definitions of quarantine and pre-shipment. Urges non-A5 Parties to refrain from MB use and use non ozone-depleting technologies whenever possible. Where MB is used Parties are urged to minimise emissions and use containment and recovery and recycling methodologies to the extent possible
VII/5	Definition of «quarantine» and «pre-shipment» applications	Provides definitions for QPS. In applying them, all countries are urged to refrain from the use of MB and to use non-ozone depleting technologies when possible. Where MB is used, Parties are urged to minimise emissions and use MB through containment and recovery and recycling methodologies to the extent possible
XI/12	Definition of pre-shipment applications	Defines a maximum time period of 21 days prior to export for application of treatments to qualify as 'Pre-shipment'
XI/13	Quarantine and pre-shipment	Requests that the 2003 TEAP Report evaluate the technical and economic feasibility of alternatives that can replace MB for QPS uses; and to estimate the volume of MB that would be replaced by the implementation of such alternatives, reported by commodity and/or application. Requests Parties to review their national regulations with a view to removing the requirement for the use of MB for QPS where alternatives exist. Urges Parties to implement procedures to monitor the uses of MB by commodity and quantity for QPS uses. Encourages the use of recycling and recovery technologies for those uses with no feasible alternatives
XVI/10	Reporting of information relating to quarantine and pre-shipment uses of methyl bromide	Requests TEAP to establish a QPS Task Force to prepare the report under Dec XI/13; requests Parties to submit information on QPS uses of MB if not already done so. Requires TF to report on the data submitted by Parties in response to the April 2004 methyl bromide QPS for the 25th OEWG. Data to be presented in a written report in a format aggregated by commodity and application so as to provide a global use pattern overview, and to include available information on potential alternatives for those uses identified by the Parties' submitted data
XVII/9	Critical-use exemptions for methyl bromide for 2006 and 2007	To request the QPSTF to evaluate whether soil fumigation with MB to control quarantine pests on living plant material can in practice control pests to applicable quarantine standards, and to evaluate the long-term effectiveness of pest control several months after fumigation for this purpose, and to provide a report in time for the 26th meeting of the OEWG.
XX/6	Actions by Parties to reduce methyl bromide use for quarantine and pre-shipment purposes and related emissions	Requests the QPSTF, in consultation with the IPPC secretariat, to review all relevant, currently available information on the use of MB for QPS applications and related emissions; to assess trends in the major uses; available alternatives; other mitigation options and barriers to the adoption of alternatives; and to determine what additional information or action may be required to meet those objectives.

XXI/10	Quarantine and preshipment uses of methyl bromide	Requests the TEAP and its MBTOC in consultation with other relevant experts and the IPPC to submit a review on the technical and economic feasibility of alternatives for a. Sawn timber and WPM (ISPM 15); b. Grains and similar foodstuffs; c. Pre-plant soil use; and d. Logs, including their current availability and market penetration rate and their relation with regulatory requirements and other drivers for the implementation of alternatives. Also requests an update on estimated replaceable quantities of MB used for QPS purposes distinguishing between A5 and non-A5 parties and a description of a draft methodology including assumptions, limitations, objective parameters and variations within and between countries that TEAP would use for assessing the technical and economical feasibility of alternatives, of the impact of their implementation and of the impacts of restricting the quantities of MB production and consumption for QPS
XXIII/5	Quarantine and pre-shipment uses of methyl bromide	Invited Parties in a position to do so to report on the amount of MB used to comply with phytosanitary requirements of destination countries, and on phytosanitary requirements for imported commodities that must be met with MB. And requested TEAP/MBTOC to summarize article 7 data on QPS and provide regional analysis; provide guidance on procedures and methods for data collection on MB use for QPS; and prepare a concise report based on responses received.
XXIV/15	Reporting on information on quarantine and pre-shipment use of methyl bromide	Requested Parties to comply with the reporting requirements of Article 7 and to provide data on the amount of methyl bromide used for quarantine and pre-shipment applications annually and invited Parties in a position to do so, on a voluntary basis, to supplement such data by reporting to the Secretariat information on methyl bromide uses recorded and collated pursuant to the recommendation of the Commission on Phytosanitary Measures. A possible request to TEAP to undertake a trend analysis of MB consumption in the QPS sector to be considered at the OEWG33 and MOP25

Source: Montreal Protocol Handbook and Ozone Secretariat website, 2015

4.5. Policies on QPS uses of methyl bromide

4.5.1. Legislation that requires methyl bromide use for QPS

Use of MB for QPS for commodity treatments is mostly associated with international trade where regulations are usually imposed by the importing country on the exporting country. MB is used in response to either pests found during inspection and/or needed for a phytosanitary certificate, which requires the commodity to be free from quarantine pests and MB may be used or certified that MB has been applied at the rate required by the importing country. The driving force for what treatments are required, allowed or not allowed are those of the importing country. In the case of bilateral trade and quarantine use, the importing country may allow the treatment to be conducted in the importing country, but often the treatment must be conducted in the exporting country. In many cases, QPS use of MB is covered by a number of national and local regulations, which often need to be considered in conjunction with one another.

There are also instances where internal regulations are imposed by national or state jurisdictions to use MB for movement of commodities across state or county borders. These relate to movement of quarantine pests that are known to be absent within the state or county.

MBTOC has encountered very few regulations that required or specified MB use only, however those that do tend to use substantial amounts of MB such as in the log trade. There are many regulations that require plants to be free of insect and other pests, with MB as the only practical fumigant available especially at portside in the importing country i.e. when inspection at the importing port finds quarantine pests fumigation with MB may be the only available way to destroy the infestation, short of destroying the shipment. In some cases where MB is not deleterious to the commodity and relatively cheap, there may be little incentive to search for alternatives especially since the alternative treatments usually have to be developed in the exporting country which may lack resources to do this.

Research to develop and confirm effectiveness of alternatives for quarantine treatments for international trade is expensive and time consuming and generally must be done in the exporting country because only they have access to the pest in question. A very high level of efficacy (often Probit 9 – LD 99.9968%) is usually required for quarantine pests where methyl bromide fumigation is used as the major or sole control step.

4.5.2. Policies and recommendations on methyl bromide and its alternatives under the International Plant Protection Convention

Some international standards produced by the IPPC (ISPMs) relate directly or indirectly to phytosanitary (quarantine) processes that either use methyl bromide at present or avoid the need for QPS methyl bromide treatments. The main standards relating to methyl bromide are:

Other ISPM standards (https://www.ippc.int/index.php?id=ispms&no_cache=1&L=0) relevant to methyl bromide treatments and alternatives are:

- ISPM No. 02 (2007) Framework for pest risk analysis
- ISPM No. 10 (1999) Requirements for the establishment of pest free places of production and pest free production sites
- ISPM No. 11 (2004) Pest risk analysis for quarantine pests including analysis of environmental risks and living modified organisms
- ISPM No. 12 (2001) Guidelines for phytosanitary certificates
- ISPM No. 14 (2002) The use of integrated measures in a systems approach for pest risk management
- ISPM No. 15 (2006) Treatment of Wood Packaging Materials
- ISPM No. 16 (2002) Regulated non-quarantine pests: concept and application
- ISPM No. 18 (2003) Guidelines for the use of irradiation as a phytosanitary measure
- ISPM No. 21 (2004) Pest risk analysis for regulated non quarantine pests
- ISPM No. 22 (2005) Requirements for the establishment of areas of low pest prevalence

- ISPM No. 24 (2005) Guidelines for the determination and recognition of equivalence of phytosanitary measures
- ISPM No. 26 (2006) Establishment of pest free areas for fruit flies (Tephritidae)
- ISPM No. 28 (2009) Phytosanitary treatments for regulated pests
- ISPM No. 29 (2007) Recognition of pest free areas and areas of low pest prevalence
- ISPM No. 30 (2008) Establishment of areas of low pest prevalence for fruit flies (Tephritidae)

The main ISPM that specifically deals with a major volume use of methyl bromide is ISPM 15, as revised (IPPC 2009b). The standard deals with the disinfestation of wood packaging material in international trade as a quarantine measure against various pests of wood and forests. The standard contains specifications for both heat treatment and methyl bromide fumigation, whilst recognising that methyl bromide is an ozone-depleting substance (IPPC 2006, 2009). The ISPM 15 standard was revised in 2009 and encourages national quarantine authorities to promote the use of an approved MB alternative: *'NPPOs are encouraged to promote the use of alternative treatments approved in this standard'* (CPM-4 report, April 2009, p.11 of Appendix 4).

ISPM 15 was updated at CPM-8 in April 2013, incorporating another heat treatment, the dielectric heating (e.g. microwave, radio frequency), for wood packaging material composed of wood not exceeding 20 cm that must be heated to achieve a minimum temperature of 60 °C for 1 continuous minute throughout the entire profile of the wood (including its surface). The prescribed temperature must be reached within 30 minutes from the start of the treatment. The Technical Panel on Phytosanitary Treatments (TPPT) accepted the treatment schedule without a thickness limit and recommended the IPPC Standards Committee to send it for member consultation.

Dielectric heating Radio frequency (RF) uses much lower frequencies than microwaves (MW), so the RF wave has a longer penetration depth than the MW, and can be used to treat wood with larger dimensions than the 20 cm accepted by ISPM 15. Another characteristic of dielectric heating (DH) is the potential for selectively heat materials, offering an advantage over conventional heating for insect control due to the selective heating of insects due to their higher water content in relation to the wood itself. Another advantage of dielectric heating systems is that they are reported to convert 50–70% of the energy to heat, in comparison to 10% efficiency in conventional ovens.

Another alternative to methyl bromide for fumigation of wood packaging material that is under review under IPPC panels and in process of approval is sulfuryl fluoride (SF). TPPT accepted 2 different schedules, one for the PineWood Nematode (PWN) and insects and other for insects only, and recommended to the IPPC Standards Committee for adoption by the CPM. The different treatments, one for wood-borne insects (less severe schedule) and for PWN and wood-borne insects (with a more severe schedule) were established because this would make the treatments more targeted and prevent unnecessarily high dosing of timber not infested with PWN. The treatments are meant to be used on debarked wood, not exceeding 20 cm in cross-section and not exceeding 60% moisture content.

Other recent reviews and recommendations that may impact MB use for QPS purposes are:

- **Cold treatments** for *Bactrocera tryoni* on oranges (*Citrus sinensis*), on tangors (*Citrus reticulata* × *C. sinensis*), on lemons (*Citrus limon*) in the process for approval. The TPPT accepted the schedules and recommended to the IPPC Standards Committee for adoption by the CPM to be included in ISPM 28.

- **Irradiation treatment** for mealybugs (Pseudococcidae) for all fruits and vegetables in the process for approval. The TPPT accepted the schedule and recommended to the IPPC Standards Committee for adoption by the CPM to be included in ISPM 28.

- **Vapour heat treatment** for *Bactrocera tryoni* on mangoes (*Mangifera indica)* in the process for approval. TPPT accepted the schedule and recommended the IPPC Standards Committee to send it for member consultation.

4.5.2.1. Phytosanitary Temperature Treatments Expert Group

The Phytosanitary Temperature Treatments Expert Group (PTTEG) was created under the support of the IPPC. The mission of the PTTEG is to provide a mechanism where critical phytosanitary temperature treatment issues can be addressed through discussion and collaborative research. The Expert Consultation on Cold Treatments (ECCT) meeting was organized by the IPPC Secretariat and hosted by the National Plant Protection Organization (NPPO) of Argentina in December 2013. The objective of the Meeting was to provide the foundation for submissions of phytosanitary treatments to be considered for International Standards for Phytosanitary Measures through the scientific input of the participants from data gathered from scientific research. Seventeen experts from 10 different countries participated.

The group agreed that any research should focus on the sound scientific reasoning behind each step of development of cold phytosanitary treatments and not detailed prescription conducting of phytosanitary treatment. The ECCT identified a series of issues to be addressed by cold treatment researchers based on scientific, technical and logistical reasons. Finally the ECCT participants agreed that work on cold treatments and networking among researchers would be useful and agreed to form a new group that would also cover all temperature phytosanitary treatments. The ECCT participants name this group "Phytosanitary Temperature Treatments Expert Group" and the scope of this group can be extended for all phytosanitary treatments in order to provide a mechanism where critical phytosanitary treatment issues can be addressed through discussion and collaborative research and providing scientific analysis and review of global phytosanitary treatments issues and new information. The group agreed to have a next meeting in August 2015 in Nelspruit, South Africa.

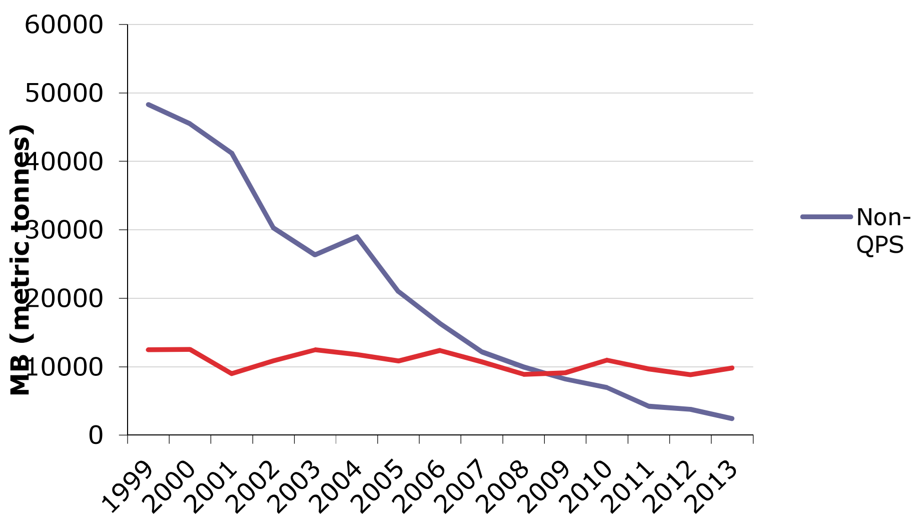
4.6. *Production and consumption of MB for QPS uses*

4.6.1. Introduction

Since 1999 there has been a continuous reduction in controlled uses of methyl bromide ("non-QPS") as alternatives have been adopted in the majority of countries countries in observance of the phase-out deadlines agreed undert the Protocol. By the end of 2013, the last date for which official consumption data were available at the time of writing this report, 88% of controlled uses of MB in Article 5 Parties and 98% of such uses in non-Article 5 Parties had been replaced.

In contrast, QPS consumption has not decreased but remained relatively constant over the last decade, as shown in Figure 4-1. In 2009 the QPS use exceeded non-QPS for the first time, being 46% higher. This was partly due to the continued decrease in the non-QPS uses, as well as recategorisation by some Parties of uses previously considered non QPS to QPS. Since 2003 an amount of methyl bromide included in the initial baseline estimates for controlled MB uses, between 1400 to 1850 t, has been recategorised to QPS MB use for the preplant soil treatment of propagation material. In 2013, reported QPS consumption was over three times larger than controlled consumption.

FIGURE 4-1: COMPARISON OF NON-QPS AND QPS CONSUMPTON IN THE PERIOD 1999 TO 2013

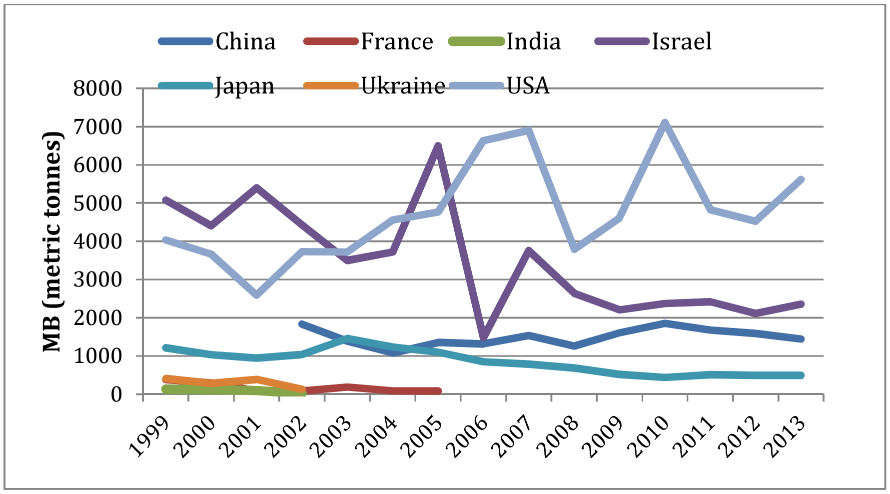


Source: Ozone Secretariat Database, January 2015

4.6.2. QPS Production trends

Global production of methyl bromide for QPS purposes in 2013 was 9,915 tonnes, increasing by about 12% from the previous year. Although there are substantial variations in reported QPS production and consumption on a year-to-year basis, there is no obvious long term increase or decrease. QPS production currently occurs in four Parties (USA, Israel, China and Japan), as indicated in Figure 4-2. According to the Article 7 reports, QPS production in France, Ukraine and India ceased by 2003, 2003 and 2006 respectively. In A5 countries, India last reported QPS production in 2002 and has not reported any production since that time. China's production each year has ranged from 1,077 to 1,836 tonnes since 2002. Compared to 2010, the quantity of QPS produced in 2013 increased in Israel and the USA, but declined slightly in China and Japan (Figure 4-2). Japan shows a reduction trend, whereas the USA and Israel have shown relatively large annual fluctuations over the last 15 years as shown.

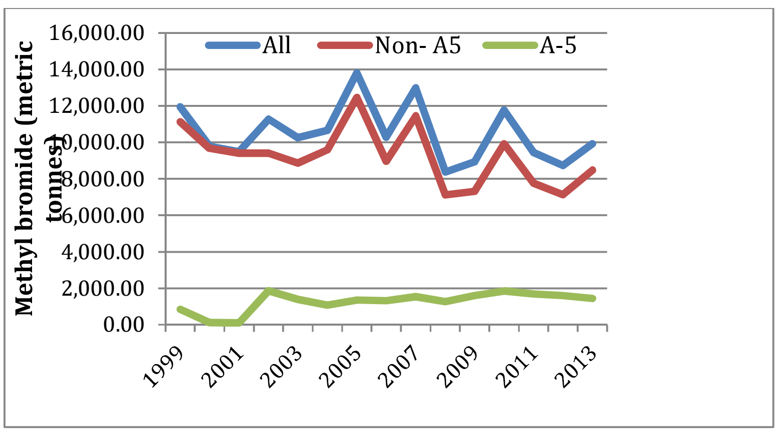
FIGURE 4-2: METHYL BROMIDE PRODUCTION FOR QPS PURPOSES, PER PARTY 1999 TO 2013



Source: Ozone Secretariat Database, January 2015

The global production trend closely follows that of non-A5 Parties (Fig. 4-3)

FIGURE 4-3: GLOBAL, NON-A5 AND A5 QPS PRODUCTION FROM 1999 TO 2013

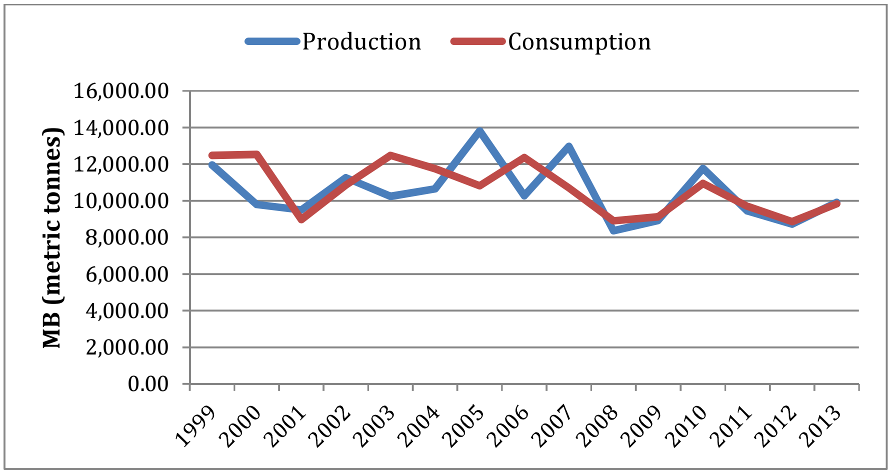


Source: Ozone Secretariat website data access centre, January 2015

4.6.3. Production vs consumption

In 2013, global QPS consumption was slightly lower than global production. However, production and consumption fluctuate from year to year (Fig. 4-4). Production has exceeded consumption in several years since 1999. It may indicate that producers produce more QPS than can be consumed in the year of production, leading to consumption that exceeds production in the following year.

FIGURE 4-4. GLOBAL CONSUMPTION AND PRODUCTION OF QPS FROM 1999 TO 2009



Source: Ozone Secretariat website data access centre, December 2014

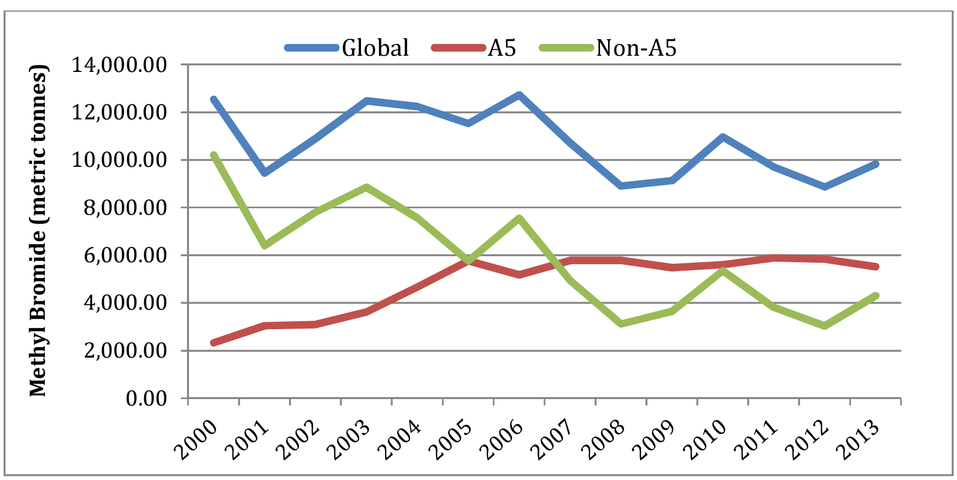
4.6.4. QPS Consumption trends

4.6.4.1. Global QPS consumption

In 2013, QPS consumption in A5 Parties (5,521 tonnes) represented 56% of global consumption; non-A5 Party consumption, at 4,307 tonnes was 46%. In 2012 the proportions were somewhat different with A5 consumption representing 66% of global consumption and non-A5 consumption 34%.

Overall however, consumption in Article-5 Parties has trended upward over the past 15 years (Fig. 4-5), whereas consumption in non-A5 Parties has trended downward over the same time period, with global QPS consumption remaining relatively stable overall. Global consumption averaged 10,850 tonnes over the period 1999 to 2013 (Fig. 4-5, top line), and in 2013 (9,830 tonnes) remained close to the average.

FIGURE4-5: GLOBAL, NON-A5 AND A5 CONSUMPTION OF QPS FROM 1999 TO 2013



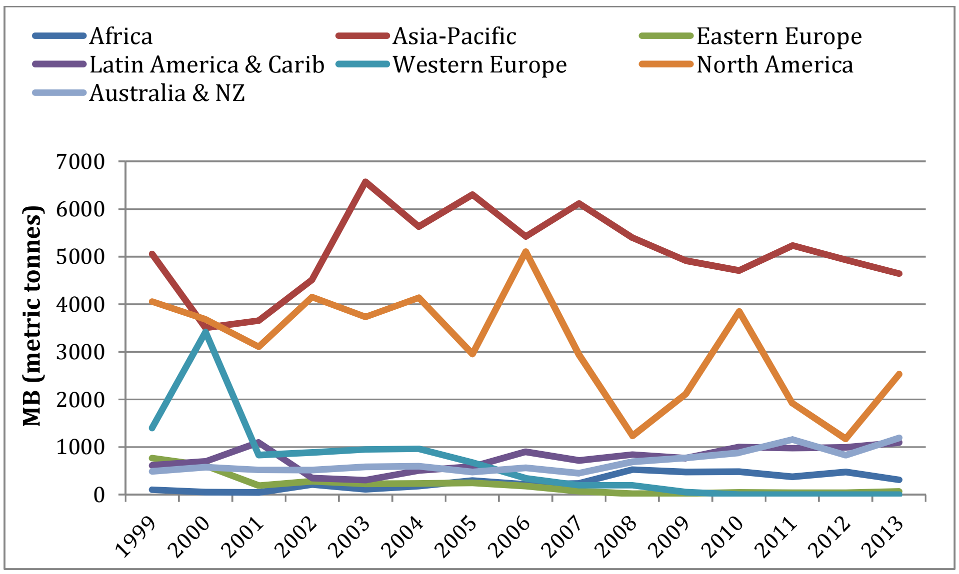
Source: Ozone Secretariat Database January 2015

4.6.4.2. Regional consumption

Regional consumption of MB for QPS purposes over the past fifteen years was analyzed on the basis of data reported by Parties for 2013. The regions shown in Figs 4-6 and 4-7 include both A-5 and non-A5 Parties when these are located in the same region.

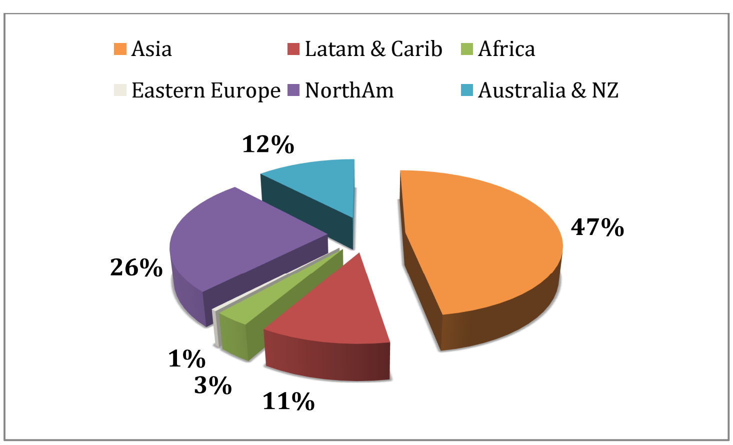
Wide variations are noted for North America (the USA comprises over 99% of this consumption since Mexico has been included in the "Latin America & Caribbean region). An upward consumption trend is noted in Australia & NZ group as well as in the African and Latin American regions.

FIGURE 4-6: REGIONAL CONSUMPTION OF QPS FROM 1999 TO 2009



Consumption in the Latin America & Caribbean, Africa and Eastern Europe regions has remained much lower since 1999 than in Asia and North America. In 2013, an analysis of global consumption (including both A5 and non-A5 Parties in the regions where appropriate), Asia consumed 4,641 tonnes, which corresponds to 47% of global QPS consumption (Fig 4-7).

FIGURE 4-7: REGIONAL CONSUMPTION OF QPS IN 2013

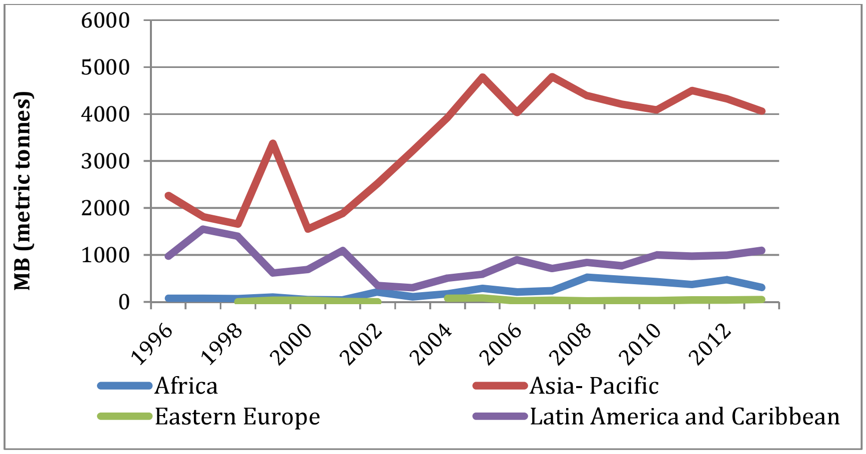


Source: Ozone Secretariat Database, January 2015

4.6.5. Article 5 QPS consumption

When considering A5 regions only, Asia emerges once again as the largest consuming region (Fig. 4-8). This region contains large consumers like China, Vietnam and the Republic of Korea. Since 2010, Latin America continues an upward consumption trend whilst Africa shows a decrease in recent years.

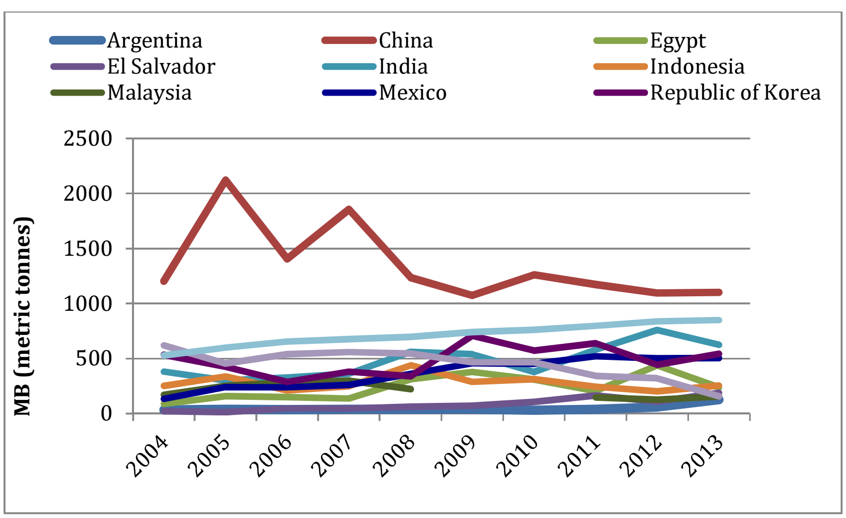
FIG. 4-8 MB QPS CONSUMPTION IN ARTICLE 5 REGIONS 1996-2013



The consumption in eleven A5 Parties that reported consumption of more than 100 tonnes in 2013 is shown in Fig. 4-9. These eleven A5 Parties accounted for 90% of the total A5 QPS consumption in 2013. China was the largest consumer in 2013 (1,102 tonnes) followed by Viet Nam (850 tonnes), India (625 tonnes), Korea (542 tonnes) and Mexico (503 tonnes).

The Ozone Secretariat database shows that seventy-three A5 Parties have reported consumption of QPS at least once in the period 1999 to 2013. A further 74 (51%) A5 Parties have never reported consumption of QPS during this period. Fig 4-9 shows the consumption trend in the eleven A5 Parties reporting consumption larger than 100 tonnes of MB for QPS in 2013 for the period between 2004 and 2013.

FIGURE 4-9 . QPS CONSUMPTION TREND IN A5 PARTIES THAT REPORTED CONSUMPTION ABOVE 100 TONNES IN 2013



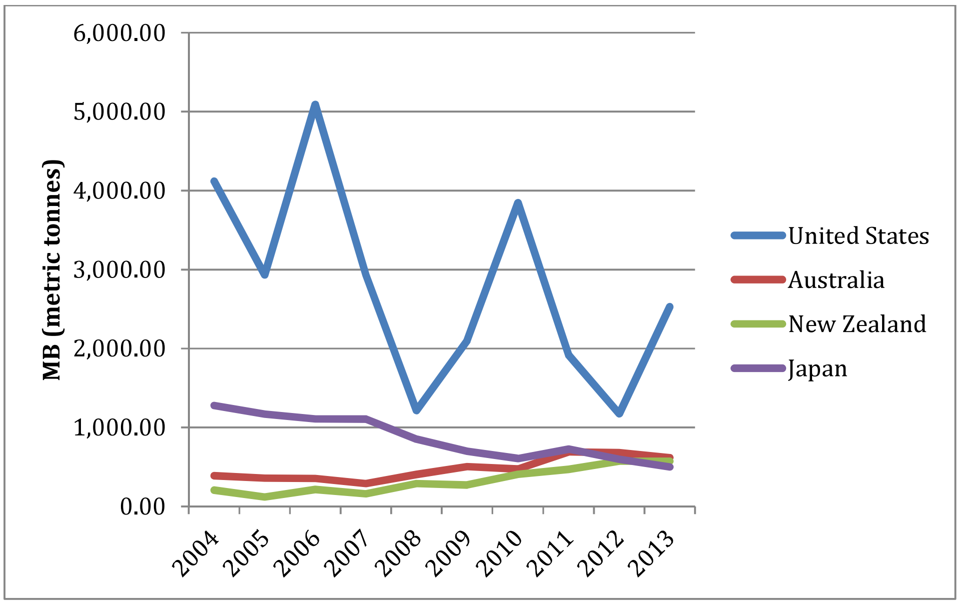
Source: Ozone Secretariat Database, December 2014

4.6.5.1. *Non-A5 QPS consumption*

The Ozone Secretariat database shows 23 non-A5 Parties had reported consumption of QPS at least once in the period 1999 to 2013. The consumption of QPS reported by non-A5 Parties in 2013 totalled 4,037 tonnes. Four non-A5 Parties consumed 98% of the QPS reported by non-A5 Parties in 2013.

Fig. 4-10 shows the consumption by the highest-consuming four non-A5 Parties from 2004 to 2013 that each consumed more than 100 tonnes of QPS in 2009.

FIGURE 4-10. TRENDS IN QPS CONSUMPTION IN NON-A5 PARTIES THAT REPORTED CONSUMPTION OF MORE THAN 100 TONNES IN 2013



Source: Ozone Secretariat Database, January 2015

The consumption reported by the USA in 2013 (2528 tonnes) was significantly larger than in 2012 (1,171 tonnes), but about 49% lower than its maximum QPS in 2006 (5,089 tonnes). Japan's consumption in 2013 (499 tonnes) continued a steady reduction trend from peak consumption in the past 10 years of 1,637 tonnes in 2000. Conversely, both Australia and New Zealand have increased QPS in each year since 2007.

The EU adopted legislation in 2008 and 2009 that banned consumption of methyl bromide including QPS from 19 March 2010.

4.7. Main Uses of Methyl Bromide for QPS purposes

4.7.1. Main individual categories of use by volume

At various stages since 1994, TEAP and MBTOC have carried out surveys and/or contacted national experts in order to compile information about major QPS uses, and to estimate methyl bromide volumes used in some cases (e.g. MBTOC 1995, 1998, 2003, 2007, 2011). More recently, MBTOC conducted a new survey on QPS uses amongst Parties reporting QPS consumption of 20 metric tonnes or larger, with help from the Ozone Secretariat; this provided a list of 31 A-5 Parties and 5 non-A5 Parties. Responses were received by more than half of these Parties, providing very helpful information to MBTOC, which was highly appreciated.

In keeping with past Decisions (i.e. XX/6), MBTOC followed the same categories of use for QPS as those used by the IPPC, with some additions and modifications. These were as used in Annex 6 of 3CPM – *Recommendation for the replacement or reduction of the use of methyl bromide as a phytosanitary measure* (IPPC, 2008) and are given in Table 4-2. The additional categories marked with an asterisk in were added to cover areas not covered by the IPPC.

TABLE 4- 2: MAIN CATEGORIES OF MB USE FOR QPS PURPOSES

Category	Uses
Commodities	Bulbs, corms, tubers and rhizomes (intended for planting)
	Cut flowers and branches (including foliage)
	Fresh fruit and vegetables
	Grain, cereals and oil seeds for consumption including rice (not intended for planting)
	Dried foodstuffs (including herbs, dried fruit, coffee, cocoa)
	Nursery stock (plants intended for planting other than seed), and associated soil and other growing media
	Seeds (intended for planting)
	Soil and other growing media as a commodity, including soil exports and soil associated with living material such as nursery stock*
	Wood packaging materials
	Wood (including sawn wood and wood chips)
	Whole logs (with or without bark)
	Hay, straw, thatch grass, dried animal fodder (other than grains and cereals listed above)
	Cotton and other fibre crops and products
	Tree nuts (e.g. almonds, walnuts, hazelnuts)
Structures and equipment	Buildings with quarantine pests (including elevators, dwellings, factories, storage facilities)
	Equipment (including used machinery and vehicles) and empty shipping containers and reused packaging
Soil as agricultural land*	Pre-plant and disinfestation fumigation of agricultural land*
Miscellaneous small volume uses	Personal effects, furniture, air* and watercraft*, artifacts, hides, fur and skins

Source: IPPC (2008) list of categories; *Not on IPPC (2008) list

4.7.2. Quantity of methyl bromide used

Dosages of MB at 80-200 g h m^{-3} mainly control insects, mites and vertebrate pests but higher rates typically exceeding 5000 g h m^{-3} are required for control of nematodes, snails and fungi; and for devitalising seeds.

A general analysis on categories of use by volume was conducted, on the basis of information received from Parties in response to the survey conducted by MBTOC in 2014 amongst key Parties, supplemented by information contained in past QPS reports (TEAP, 2009, MBTOC, 2011, TEAP, 2012) as well as data from previous surveys of QPS uses (TEAP 2006, UNEP/ ROAP 2008).

While there remain some data gaps and uncertainties, MBTOC (and previously the QPSTF) were able to make estimates that covered more than 80% of total global 2013 reported QPS use or consumption by volume, with over 75% of this resulting from 5 major categories of use as shown in Fig. 4-11. There were some differences in these categories when comparing A5 vs non-A5 (Figs 4-12 and 4-13). This analysis confirmed that the five largest consuming categories of methyl bromide for QPS:

1) Sawn timber and wood packaging material (ISPM-15)
2) Grains and similar foodstuffs
3) Pre-plant soils use and
4) Logs.
5) Fresh fruit and vegetables

The first four uses consumed more than 80% by weight of the methyl bromide used for QPS in 2013. These findings are generally consistent with previous MBTOC reports (TEAP, 2009; MBTOC, 2011). On the basis of these estimates, TEAP calculated in 2009 that 31% to 47% of global consumption in 2008 by the first four categories of use could be replaced with available alternatives (TEAP, 2009; 2010).

FIGURE 4-11. ESTIMATED GLOBAL CATEGORIES OF MB USE (QPS PURPOSES) IN, 2013

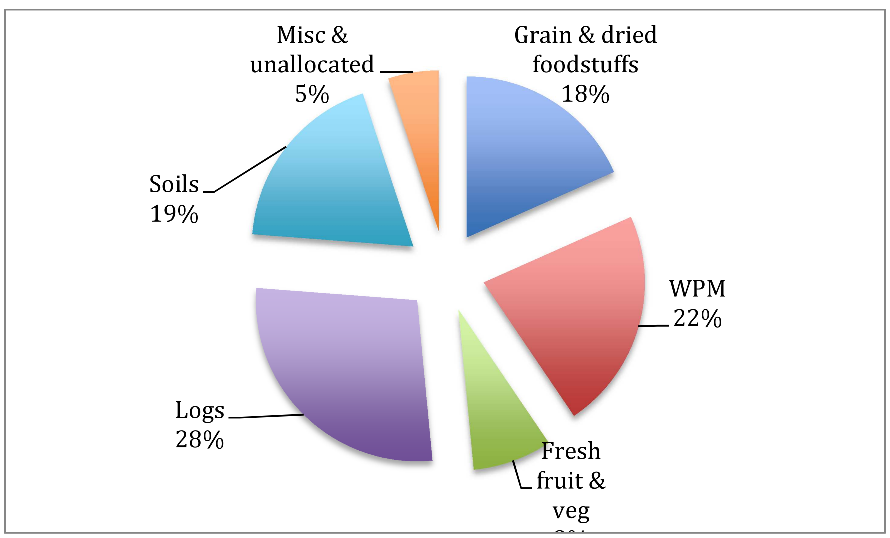


FIGURE 4-12 . ESTIMATED CATEGORIES OF MB USE (QPS PURPOSES) IN ARTICLE 5 PARTIES IN 2013

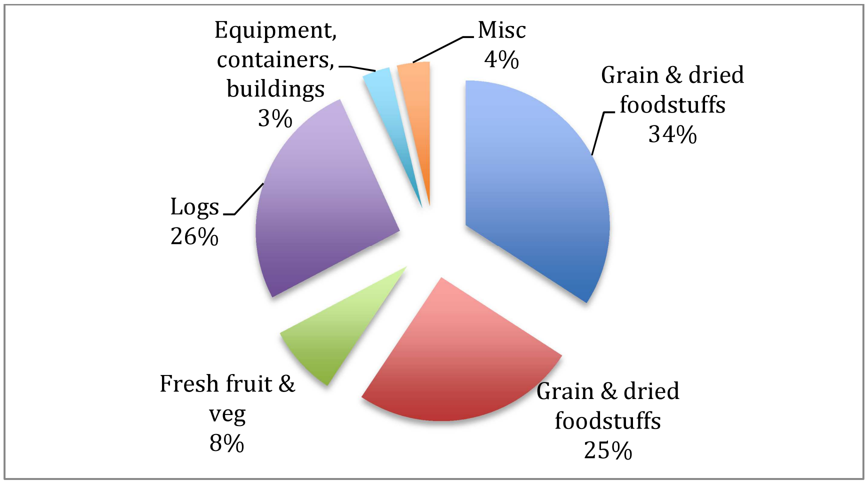
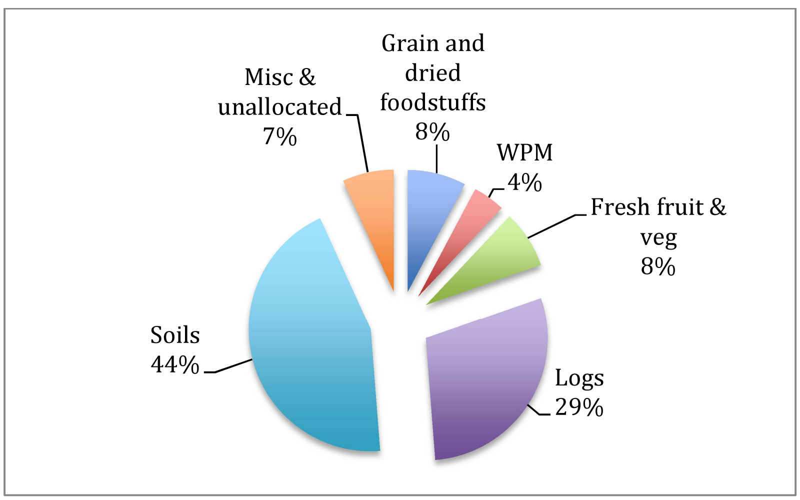


FIGURE. 4-13. ESTIMATED CATEGORIES OF MB USE (QPS PURPOSES) IN ARTICLE 5 PARTIES IN 2013



Sources: MBTOC survey of QPS uses in A5 parties with reported consumption at or above 100 tonnes; 2010 MBTOC Assessment Report; 2009 TEAP/ MBTOC Reports (TEAP, 2009, 2010); Rodas, 2013; NOUs, regional networks and national experts

4.8. Key quarantine pests controlled with methyl bromide

Target pests for QPS treatments vary from country to country even for the same commodity, and the procedures for handling the issue of defining the target pests may also differ.

For pre-shipment treatments required by official authorities, the objective of treatments is to produce goods that are 'pest-free', or sometimes to some standard sampling level. While in practice the target species are typically insect pests (beetles, moths and psocids) that are widely distributed and associated with quality losses in storage, treatments are also expected to eliminate the other living insect species that may contaminate commodities during harvesting, storage and handling, even when they do not pose a direct threat to the quality of the commodity.

For quarantine treatments, the National Plant Protection Organisations (NPPOs) of particular countries publish master lists of regulated pests, being recognised quarantine pest species. These can be found through the IPPC portal. Only some of these pests are controlled by methyl bromide as the treatment of choice or exclusive approved treatment. Some quarantine authorities have regulations for species not found in their country that require quarantine action if the species is known to be a pest that would cause damage or vector diseases in their country or if there is evidence to suggest a risk of such damage. Likewise species that would substantially endanger human or animal health or comfort, especially by spreading exotic disease, would likewise be considered a quarantine species. Species of quarantine concern to one country will not necessarily be of concern to another country: the pest might attack a crop not grown in the country, climatic conditions in the country might not be favourable to establishment of the species or the country might already have the species in their country. Nonetheless, there are certain groups of organisms that are responsible for most quarantine action in the world currently involving methyl bromide treatment.

Table 4-3 shows the main target pests of quarantine significance in the major classes of methyl bromide use, by volume, for plant Quarantine purposes.

TABLE 4-3: MAIN TARGET PESTS OF PLANT QUARANTINE SIGNIFICANCE IN THE MAJOR CLASSES OF MB USE FOR QPS PURPOSES

Treated commodity or situation	Main target quarantine pests
Whole logs, not debarked	Various species of bark beetles, wood borers, Sirex spp., pinewood nematodes, fungi (oak wilt, *Ceratocystis ulmi*).
Solid wood packaging	Various species of bark beetles, wood borers, Sirex spp., pinewood nematodes (*Bursaphelenchus xylophilus*).
Grain and similar foodstuffs	*Trogoderma* spp., particularly *T. granarium*; *Prostephanus truncatus*; *Sitophilus granarius*; cotton boll worm, various snails.
Fresh fruit and vegetables	Numerous species of Tephritidae (fruit flies), thrips, aphids, scale insects and other sucking bugs, various Lepidoptera and Coleoptera, various mites.
Soil for crop production, including propagation material	Exotic nematodes such as the Pale Potato Cyst Nematode (*Globodera pallida)*,Golden nematode (*Globodera rostochiensis)*,, exotic weeds, including *Orobanche* spp. Regulations in the USA also allow general ‘certification’ of nematodes to be considered QPS.

Key quarantine pests that are sometimes controlled in international trade with methyl bromide that lie outside the scope of the IPPC include various mosquito species (human and animal disease vectors, nuisance species), tramp ant species including red imported fire ant (*Solenopsis invicta*) (animal and ecological health, invasive species), rodents (disease vectors, stored product pest), snakes (invasive species), and cockroaches (human health disease vectors).

4.9. Existing and potential alternatives for the major QPS use categories

Previous MBTOC and TEAP reports have provided details of existing alternatives for various QPS uses (e.g. MBTOC 1995, 1998, 2002, 2007; TEAP 1999, 2007, 2009, 2010). The 2002, 2006 and 2010 MBTOC Assessment Reports (MBTOC 2002, 2007, 2011) provided detailed discussion of alternatives to QPS methyl bromide use on commodities in specific circumstances. Detailed reports on QPS and alternatives are further given in TEAP (2003), produced in response to Decision XI/13(4) and in TEAP (2009 ab, 2010) in response to Decisions XX/6 and XXI/10.

Existing alternatives to MB for QPS treatment of perishable and durable commodities are based on

1. Pre-harvest practices and inspection procedures
2. Non-chemical (physical) treatments and
3. Chemical treatments.

Many quarantine treatments are ‘post-entry’. This is where a treatment is required either if inspection finds a quarantine organism in the shipment at the port of entry or quarantine or other treatments have been insufficient to adequately manage the risk of importing quarantine pests in sufficient numbers to be a quarantine threat. Many countries prohibit imports of particular cargoes where the risk of carrying quarantine pests is unacceptable and there is no system or treatment available to manage this risk to an adequate level. This avoids the need for post-entry quarantine measures, including methyl bromide fumigation.

Treatment options are often more restricted for post-entry quarantine treatments than for pre-shipment. In many post-entry situations, fumigation with MB is the only technically and economically available and approved process to meet quarantine standards to allow importation, due to limited infrastructure to apply alternative. Cargos are often containerized and removal (unpacking and treating) from the container is uneconomic. MB fumigation may be ordered before the commodity can be released for distribution and rejection or destruction remains the default option if the treatment is not carried out.

NPPOs may publish listings of approved treatments for imports, with specifications varying according to phytosanitary requirements of receiving countries and pest risk. MB may be specified as a quarantine treatment, but often there are also approved alternatives. A listing of alternatives for various Quarantine uses was given in the IPPC recommendation (IPPC 2008) to its contacting Parties on preferential use of alternatives in place of MB, together with considerations affect the choice of a phytosanitary measure to replace methyl bromide use. The listing is reproduced in Table 4-4.

Additional information on alternatives to MB for the main QPS uses is provided below. The reader is strongly encouraged to also consider the documents described at the beginning of this section.

TABLE 4-4: EXAMPLES OF POTENTIAL PHYTOSANITARY TREATMENTS THAT CAN REPLACE OR REDUCE METHYL BROMIDE USE FOR QPS PURPOSES

List of articles fumigated	Examples of phytosanitary treatments to consider to replace or reduce methyl bromide[3]
Bulbs, corms, tubers and rhizomes (intended for planting)	Hot water, pre-plant quarantine soil sterilization (steam or chemical), pesticide dip, or a combination of these treatments
Cut flowers and branches (including foliage)	Controlled atmosphere (CO2, N2) + combination treatment, hot water, irradiation, phosphine, phosphine/carbon dioxide mixture, pyrethroids + carbon dioxide, ethyl formate + carbon dioxide
Fresh fruit and vegetables	Cold treatment, high-temperature forced air, hot water, irradiation, quick freeze, vapour heat treatment, chemical dip, phosphine, combination of treatments, ethyl formate + carbon dioxide
Grain, cereals and oil seeds for consumption including rice (not intended for planting)	Heat treatment, irradiation, ethyl formate, carbonyl sulphide, phosphine, phosphine + carbon dioxide, sulfuryl fluoride, controlled atmospheres (CO2, N2)
Dried foodstuffs (including herbs, dried fruit, coffee, cocoa)	Heat treatment, carbon dioxide under high pressure, irradiation, ethyl formate, phosphine, phosphine + carbon dioxide, controlled atmosphere (CO2, N2), sulfuryl fluoride, propylene oxide-+-
Nursery stock (plants intended for planting other than seed), and associated soil and other growing media	Hot water, soil sterilization (steam or chemical e.g. methyl isothiocyanate (MITC) fumigants), pesticides dip, phosphine, combination of any of these treatments
Seeds (intended for planting)	Hot water, pesticide dip or dusting, phosphine, combination treatments
Wood packaging materials	Heat treatment, now including dielectric heating (contained in Annex 1 of ISPM No. 15 and its revisions). Further alternative treatments may be added in the future.
Wood (including round wood, sawn wood, Wood chips)	Heat treatment, kiln-drying, removal of bark, microwave, irradiation, MITC/sulfuryl fluoride mixture, methyl iodide, chemical impregnation or immersion, phosphine, sulfuryl fluoride
Whole logs (with or without bark)	Heat treatment, irradiation, removal of bark, phosphine, sulfuryl fluoride. MITC/sulfuryl fluoride mixture, methyl iodide.
Hay, straw, thatch grass, dried animal fodder (other than grains and cereals above)	Heat treatment, irradiation, high pressure + phosphine, phosphine, sulfuryl fluoride
Cotton and other fibre crops and products	Heat treatment, compression, irradiation, phosphine, sulfuryl fluoride CO_2
Tree nuts (almonds, walnuts, hazelnuts etc.)	Carbon dioxide under high pressure, controlled atmosphere (CO2, N2), heat treatment, irradiation, ethylene oxide, ethyl formate, phosphine, phosphine + carbon dioxide, propylene oxide, sulfuryl fluoride
Buildings with quarantine pests (including elevators, dwellings, factories, storage facilities)	Controlled atmosphere (CO2, N2), heat treatment, pesticide spray or fogging, phosphine, sulfuryl fluoride
Equipment (including used agricultural machinery and vehicles), empty shipping containers and reused packaging	Controlled atmosphere (CO2, N2), heat treatment, steam, hot water, pesticide spray or fogging, phosphine, sulfuryl fluoride
Personal effects, furniture, crafts, artefacts, hides, fur and skins	Controlled atmosphere (CO2, N2), heat treatment, irradiation, ethylene oxide, pesticide spray or fogging, phosphine, sulfuryl fluoride

[3] Examples are given that are generally applicable and likely to meet prevailing standards for treatment or disinfestation. Some alternatives may not be appropriate on particular commodities within the general category or in specific situations.

4.9.1. Sawn timber and wood packaging material (WPM)

This section excludes logs and covers only quarantine treatments of wood that has been sawn into lumber and wooden packaging material derived from sawn timber. This material is mostly free of bark, but may include sapwood as well as heartwood. Sapwood is often present in lumber and can contain insects even in logs that have been debarked. For imports of lumber into some countries such as China and Korea do not require fumigation but inspect on arrival and fumigate if pests are detected; other countries such as India require fumigation of lumber containing sapwood. Japan sapwood is categorized as logs and it is inspected and treated in import quarantine (MBTOC, 2011). Sawn timber may be traded or made into pallets, dunnage and other packing material associated with either international or domestic trade.

4.9.1.1. Heat treatment

The only alternative treatment to methyl bromide treatment approved and accepted internationally under ISPM-15 for treatment of wood packaging materials (wood packaging material) is heat treatment, including kiln drying and more recently dielectric heating (e.g. microwave) see section 4.5.3. When using heat treatment (including kiln drying), a temperature of at least 56°C, core temperature, must be maintained for at least 30 minutes (IPPC 2006). For dielectric heating, a schedule of 60ºC for one minute throughout the entire profile of wood without a thickness limit has been accepted (IPPC 2011, 2013a).

Dielectric heating Radio frequency (RF) uses much lower frequencies than microwaves (MW), so the RF wave has a longer penetration depth than the MW, and can be used to treat wood with larger dimensions than the 20 cm accepted by ISPM 15. It also has the potential to selectively heat materials and is more energy efficient than conventional ovens.

The revised version of the ISPM-15 standard (IPPC 2009) specifically encourages the use of heat where feasible in preference to methyl bromide, because of the ozone-depleting properties of methyl bromide.

The use of the heat treatment in many countries to meet ISPM-15 is substantial and continues to increase. In general, heat treatment requires a somewhat higher level of infrastructural support compared with MB, but has been shown to be cost effective and practical in many locations. A variety of facilities are in use to achieve the specified heat dosage for ISPM-15. They include timber kilns (present in many countries), modified freight containers or similar enclosures with either hot water heating (China) or electrical or gas heating (Australia, Jamaica, New Zealand, Japan and EU member states). Heat has been used in many Article 5 countries for many years (e.g. Morocco, Colombia, Argentina, Mexico and Ecuador). A recent review (Rodas, 2013) indicates that several countries in Central America – Guatemala, Honduras, Costa Rica and Panama – treat between 70 and 100% of their WPM with heat to comply with ISPM-15 regulations. Heat treatments are reported as economically feasible and easy to implement due to the fact that they can be integrated with kiln drying.

Kiln drying of sawn timber (lumber) exceeds the temperature thresholds and duration criteria defined in ISPM-15, thereby providing an alternative quarantine treatment to methyl bromide where insect and nematodes are pests of quarantine concern. Higher temperatures are required for control of fungi, but some timber (especially hardwoods) can be damaged by the high temperature treatment.

Microwave heat treatment is likely to be more economically viable, particularly in a pass-through conveyor configuration designed to eradicate wood materials infected with pinewood nematode, this is because dielectric modalities such as microwaves heat polar molecules through the profile of the wood simultaneously (Hoover *et al*., 2010).

4.9.1.2. Chemical alternatives

Fumigation is preferred when goods are present on wood packaging material that needs to be disinfested to meet the requirements of ISPM-15, and the goods are likely to be damaged by heat.

The only officially-recognised chemical option at present is methyl bromide but sulfuryl fluoride, and phosphine continue to be under consideration. SF fumigation of WPM is now in the process for approval. TPPT accepted 2 different schedules, one for the PineWood Nematode (PWN) and insects and other for insects only; and recommended to the IPPC Standards Committee for adoption by the CPM. The different treatments, one for wood-borne insects (less severe schedule) and for PWN and wood-borne insects (with a more severe schedule) were established because this would make the treatments more targeted and prevent unnecessarily high dosing of timber not infested with PWN. The treatments are meant to be used on debarked wood, not exceeding 20 cm in cross-section and not exceeding 60% moisture content (IPPC, 2013ab).

In 2013, synthetic pyrethroid usually applied premixed and propelled by CO_2 has replaced several tonnes of MB for the treatment of containerised export sawn timber infested with hitchhiking adult *Arhoplusferus* beetles during the summer when being shipped from New Zealand to Australia.

Some National Plant Protection Organisations recognise other treatments for wood packaging material and similar products, instead of methyl bromide or heat treatments undertaken according to the treatment criteria contained in ISPM-15. These treatments may be post entry or prior to export and are generally based on bi-lateral agreements between countries interested in a specific trade. Australia, for example, requires off shore treatments of timber packaging and dunnage that have not been treated in accordance with ISPM-15 to be treated at specified dosages of several alternatives, including fumigation with sulfuryl fluoride, or ethylene oxide or treatment with heat, gamma irradiation or some timber preservatives (ICON 2009).

4.9.1.3. Alternatives to wood pallets and other wooden packaging materials.

Alternative packaging methods avoid the need for methyl bromide fumigation or heat treatment. Plastic pallets (often made from recycled plastic) are commercially available and are used by many companies in the EC, the US and many other regions of the world. Cardboard pallets can be suitable for loads of about 3,000 kg and are available commercially in Australia, the EC, Kenya, New Zealand, the US and others. These materials are exempt from the requirements of ISPM-15.

Particularly in Article 5 Parties, the added expense of using alternative materials to wood as well as in some cases lack of raw materials with which to make such pallets, places constraints on access to pallets that are not made of wood. The reuse of ISPM 15 compliant wood packaging is common.

4.9.2. Alternatives for logs

There is active research in progress to develop alternatives for logs but gaining the required efficacy data is difficult as laboratory rearing has not yet been achieved to the numbers required. Most insects are seasonal, and the commodity is large and variable.

Methyl bromide is the most widely used fumigant for logs, however it does have some limitations including limited penetration across the grain and into wet timber. Most arthropods associated with timber are quite susceptible to methyl bromide but much higher dosages are required to kill fungi (Rhatigan *et al.,* 1998). Green logs are problematic to treat due to the high moisture content (80%), presence of bark (very adsorbent), size and large volumes. Overall, methyl bromide is currently the best log fumigant that is registered and available.

Treatments of logs may need to be rapid, such as at point of export or import, to avoid charges and congestion at ports associated with occupying restricted port area for the treatment. Where quarantine treatments can be applied outside port areas, such as prior to export or in-transit, alternatives to methyl bromide that take a longer time can be used. Many pests of quarantine significance, which attack green wood, do not re-infest dry and debarked wood.

Specific QPS alternatives for logs are discussed below, followed by discussion of some processes under development.

4.9.2.1. Reduction in methyl bromide dosage

Treatment specifications for logs have not been harmonised worldwide and schedules vary with the importing country of import and the target pest, given that quarantine security requirements are set by the importing country in accordance with their unique quarantine requirements—a right guaranteed by the World Trade Organization. For example, Korea requires 25 gm^{-3} for 24h at 12-15°C (Yu *et al.* 1984), India 64gm^{-3} 11-15^{o}C, China 120 gm^{-3} for 16h at 5-15°C, and Malaysia requires 128 gm^{-3} for 24 hour exposure at the higher temperature of 21°C. Nevertheless, significant savings of methyl bromide could be achieved by reducing the fumigation rate in situations where the use can be shown to be excessive.

4.9.2.2. Phosphine

New Zealand has pioneered the use of phosphine for the in-transit fumigation of *Pinus radiata* logs destined for China. It is now routinely used as a quarantine and pre-shipment measure, which unlike MB can be applied in-transit, and has partially replaced methyl bromide for this purpose. However, phosphine in-transit can only be used to treat logs shipped below deck in the holds, which are about two-thirds of each shipment.

Phosphine is less expensive than methyl bromide for the treatment of logs when it is applied at the point of export as an in-transit treatment. On longer transits phosphine can be more cost effective than methyl bromide. This is because, compared to methyl bromide, the dosage rate is lower, and it is faster to apply which reduces costly moorage time in the port. The sailing time is sooner as the ship avoids having to stay in port for at least 36 hours while the hold is fumigated and then vented. A fumigation technician is required for the voyage to add more fumigant, monitor for leaks and vent the holds. This method can only be used for logs stowed in the holds, which is normally about two-thirds of the cargo, and the balance of the cargo on deck must be fumigated with methyl bromide under tarpaulin on the wharf prior to export.

4.9.2.3. Sulfuryl fluoride

Sulfuryl fluoride is a similar fumigant to methyl bromide except that the fumigation temperature or concentration usually needs to be higher to achieve the same level of pest mortality for all stages including the egg stage. Sulfuryl fluoride is reported to have a large global warming potential (Papadimitriou *et al.,* 2008). Data continues to be collected in the USA and China on the efficacy of sulfuryl fluoride for controlling wood pests as an alternative for the disinfestation of logs. Sulfuryl fluoride penetrates timber somewhat better than does methyl bromide (Scheffrahn and Thoms, 1993; Ren and Lee, 2010).

Sulfuryl fluoride is registered or licensed for use in many countries including the Australia, EU, Japan, US and Canada, and is one of the most promising equivalent replacements for MB for logs and sawn timber, having similar properties and exposure requirements, with significantly better penetration of wood (Scheffrahn *et al*., 1992). Registration activities are in progress in China and India (Jeffers *et al.,* 2012).

There is a perception that sulfuryl fluoride will not control egg stages of quarantine pests and will not work at common ambient temperatures. Dow AgroSciences believes that good efficacy on eggs is possible by adjusting exposure rates and/or times (Scott Boothey, pers. comm.) Adoption of SF may further be constrained by its cost

4.9.2.4. EDN

Ethanedinitrile or EDN, also known as cyanide is now registered in Australia for the treatment of logs and timber, however the controls on the use such as buffer zones, recapture and withholding period mean that there has been little uptake to date. Export logs to China continue to be treated with methyl bromide as currently only Malaysia accepts EDN as a quarantine treatment.The registration process is also progressing in New Zealand, SE Asia, South Africa, Israel and being reviewed in a number of additional countries. Market acceptance tests are currently being run in many of these regions as well (Jessup et al, 2012).

4.9.2.5. Other fumigants

Recent research in the Czech Republic (Stejzkal *et al*, 2014) reports promising results with HCN (hydrogen cyanide) for controlling pinewood nematodes (*Bursaphelenchus* *xylophilus*) and Asian longhorned beetles (*Anoplophora glabripennis*) in wood and timber. Penetration rates of HCN into wooden blocks as well as its biological efficacy against these pests were evaluated.

Research on alternatives for logs evaluating the efficacy of MI and MITC/SF mixtures has been completed in Japan and both treatments are under the process of inclusion under the relevant regulations.

4.9.2.6. Heat

Heat treatment has been accepted as a quarantine treatment for logs and timber to be shipped to the USA and many other countries for many years (e.g. USDA 1996). The general specification requires the wood to reach a core temperature of 71°C for 60 minutes. Kiln drying of timber to a moisture content of less than 20% using temperatures over 70°C is often a commercial requirement but also has long been accepted as a quarantine treatment by most importing countries. Currently, 56°C core temperature for 30 minutes is required under ISPM-15 for wood packaging material.

Heat treatment of unprocessed logs is an approved risk mitigation measure for importation into the USA (Morrell 1995). Steam heat is a more effective quarantine measure than dry heat (USDA 1994; Dwinell 2001). Moist heat treatment is an integral part of log conditioning prior to peeling and has the additional benefit of eliminating quarantine pests.

4.9.2.7. Irradiation

Gamma irradiation is currently approved for the disinfestation of logs into Australia at a rate of 10 kGy (1.0 Mrad). However, its practical application must overcome a number of hurdles, not the least being the construction of large irradiators to handle logs and bulk wood products.

Irradiation is limited by poor penetration into freshly cut logs, potential damage and dose-dependent degradation of wood products such as fibre board and paper, variation in effect on different insect groups, and very high dosages required to eliminate fungi (Morrell 1995). No continuing work on irradiation treatment of logs is known to MBTOC.

4.9.2.8. Water soaking or immersion

Water soaking or immersion provides a way to control pests on imported logs. Immersion of some logs destined for plywood manufacture is a useful process as it improves the quality of the products. The storage of logs in water or under water spray has long been accepted as an effective treatment for terrestrial insects and fungi. Salt water immersion of logs for 30 days is an approved treatment for logs into Japan but contamination of waterways with bark is an issue. The upper surface of the logs above the water level is sprayed with an insecticide mixture such as dichlorvos as part of the pest management strategy (Reichmuth 2002).

The potential for use of water soaking for quarantine treatment of imported logs is limited by the large area of water required and the undesirable side effects of ponding large volumes of logs, making its application on a large scale unlikely.

4.9.2.9. *Debarking*

Bark removal has long been a key strategy in reducing contamination of logs and a way to reduce the risk of logs and sawn timber carrying certain insects and fungi of quarantine concern. While debarking removes surface contamination and also bark and cambium, which are areas particularly prone to pest attack, it does not affect insects and fungi already in the wood (USDA 1992). Many countries require debarking of all imported logs. Because of the high cost, and the requirement by customers in major Asian markets that bark remain on logs, its application as a quarantine treatment is limited and frequently only carried out on high value logs.

4.9.3. Alternatives for grains and similar foodstuffs

Methyl bromide fumigation continues to be used for pre-shipment treatment of cereal grains where logistical constraints at point of export, or importing country specifications, preclude the use of alternatives, mainly phosphine.

There are different alternative treatments of choice for grains to meet appropriate QPS standards, depending on whether the treatment is officially required by national authorities for common and cosmopolitan insects that attack or are associated with grain in storage and transport (i.e., pre-shipment), or they are for control and elimination of specific regulated quarantine pests.

Export cereal grains, such as rice and wheat, are prone to infestation by a number of cosmopolitan grain pests that cause damage when in storage and are unacceptable to modern market standards. Most of the methyl bromide fumigations are pre-shipment treatments that target non-quarantine pests. These pre-shipment treatments are officially required by official regulations of some exporting countries or by official requirements of some importing countries. Examples of pre-shipment treatments have been reported previously (TEAP 1999, 2002; MBTOC 2002, 2011). Export cereal grains, similar products and associated packaging from some locations may also be subject to quarantine treatments against specific insect pests, notably Khapra beetle (*Trogoderma granarium*), *Prostephanus* species or contaminants such as specific snails (e.g. *Cochlicella* spp.) or seed-borne diseases such as Karnal bunt (*Tilletia indica*).

Many countries have strict quarantine regulations on grain and other durables originating from countries where Khapra beetle occurs. Typically, only methyl bromide treatment is specified against this quarantine pest, using double normal dosages for stored product disinfestation often with extended exposure period. For instance, cereal products from Khapra beetle areas for import into Australia require 80 gm^{-3} of methyl bromide for 48 hours at 21°C with an end point concentration at 48 hours of 20 gm^{-3} (ICON 2009).

4.9.3.1. *Alternatives for quarantine treatments*

Methyl bromide treatment of grains for quarantine purposes continues to be often the only accepted and convenient treatment in many cases. There appear to be no drivers away from this situation in the absence of measures to curtail methyl bromide use for QPS purposes.

The USDA PPQ Treatment Manual (USDA 2009) contains many treatment schedules specific to Khapra beetle and most involve fumigation with methyl bromide. Heat treatment at a high temperature and prolonged exposure (7 minutes at 65.5°C) is given as the only approved alternative to methyl bromide and can only to be used when specifically authorised by the APHIS.

Heat treatment is a good alternative to methyl bromide for controlling many stored product pests, including Khapra beetle. Despite its tolerance to temperatures of about 41°C, Khapra beetle is quite susceptible at higher temperatures, more so than some common storage pests such as *Rhyzoperta dominica*. There are old but good quality data to substantiate heat susceptibility of stored product pests in general (see MBTOC, 2011).

In the past, *T. granarium* was quite susceptible to phosphine e.g. Hole *et al.* (1976), which made phosphine a potential alternative to methyl bromide against this pest. However, with the frequent development phosphine resistance by *T. granarium* in the Indian subcontinent, phosphine is not currently an option for controlling this pest.

Some winter wheat fields in Texas were infected with Karnal bunt disease, *Tilletia indica*, in 2001. Karnal bunt was detected in Arizona in March 1996, in Texas in 1997 and in South Africa in 2000 (Staphorst, pers. comm, 2014). The 2001 detection in Texas was significant because it occurred outside the quarantine area in Texas (J. Schaub pers. comm. 2010). When infected grain was harvested and transferred to storage bins, the bins and grain handling equipment became infected. Methyl bromide fumigation of emptied contaminated storage bins requires a high dosage (240 gm^{-3}) for 96 hours to meet quarantine standards. Steam heating to a point of runoff in bins also is an effective alternative to methyl bromide providing surface temperatures reach 77°C (Dowdy 2002). Microwave technology used in laboratory tests was reported as effective in controlling Karnal bunt (*Tilletia indica)* teliospores in 10 seconds compared to 96 hours using methyl bromide (Ingemanson, 1997). Scale up to large quantities of grain is problematic.

Japan imports about 30 million tonnes of grain including wheat, maize and soybean. Methyl bromide is the fumigant of preference for treatment of these imports. There is no approved treatment schedule other than methyl bromide where granary weevil (*Sitophilus granarius*) is detected in the grain. This flightless pest, widespread in most countries, is a listed object of quarantine in Japan. The quantity of methyl bromide used for grains in Japan is larger than for any other category except whole logs (PPS 2007). Phosphine fumigation using aluminum phosphide tablets has been included in the plant quarantine treatment schedule in Japan (MAFF, 1971). The treatment with phosphine takes many days and is thus unsuitable where there is insufficient capacity at import ports to allow long holding periods. Methyl bromide treatments typically take less than 48h. Phosphine is not accepted for controlling *Sitophilus* because the pupal stage could not be killed completely at the dosage rates and fumigation conditions used in commercial quarantine fumigation (Mori and Kawamoto, 1966). On the other hand, sulfuryl fluoride has higher efficacy against pupal stages of several stored product insects, although the egg stage is the most tolerant (Furuki *et al.* 2005; Bell *et al.,* 2003). Fumigating with a mixture of phosphine and sulfuryl fluoride gas kills all stages of *Sitophilus* species, using the good properties of both fumigants. Tests with mixtures of phosphine and sulfuryl fluoride were conducted in Japan and a sequential fumigation that consists of a sulfuryl fluoride fumigation for 24 hours and a phosphine fumigation for 48 hours was decided to be effective to eliminate all stages of Sitophilus species (Misumi et al., 2011).

Freezing has been used successfully for controlling the coffee berry borer, *Hypothenemus hampei*, in green coffee. *H. hamoei* is a serious pest of coffee which, although reported in many coffee growing countries, is generally classified as a quarantine pest to delay spread or avoid reintroductions. Temperatures in the range of −13.9 to −15.5 ºC for 48 h were found to provided 100% control of all life stages and the treatment appeared more economical and acceptable compared with fumigation with methyl bromide, especially for small-scale and organic growers and millers in Hawaii who ship green coffee beans to other islands for custom roasting (Hollingsworth *et al.,* 2013).

Alternative treatments to methyl bromide are needed for various snails of quarantine significance (e.g. *Achitina fulica*, *Cernuella* spp. *Theba pisana*). Methyl bromide fumigation is usually the only approved quarantine measure for these pests when associated with grain shipments. Other processes, including HCN and CO_2 fumigations, may be more effective (e.g. Cassells *et al.,* 1994), but are not approved and not registered.

4.9.3.2. Alternatives for pre-shipment treatments

Methyl bromide fumigation was used widely in the past to fulfill requirements for pre-shipment treatment of grain. In general, other processes are cheaper and more convenient and methyl bromide use for this purpose has decreased to the stage where it is typically used only in situations where the rapid action of methyl bromide confers technical and economic benefits.

There are well known, standard processes for protection and disinfestation of stored grain in storage and transport. Grain and similar dry foodstuffs, either bagged or in bulk, can be delivered to an export point in a '*pest-free'* condition without recourse to methyl bromide fumigation (see MBTOC 2007, 2011). The choice of alternative is dependent on the commodity or structure to be treated, the situation in which the treatment is required, the accepted level of efficacy and the cost and the time available for treatment. Some alternatives (e.g. some fumigants, heat treatment) may be implemented as 'standalone' or 'in-kind' treatments to replace methyl bromide whilst others may be used in combination to achieve the required level of control.

These processes, theoretically, can avoid the need for any further treatment against infestation at the export port. In practice, consignments may be brought to the export point in infested condition. Also, particularly in humid, tropical situations, there is often a high invasion pressure from pests at the export point. As a result, an insecticidal process (usually fumigation) must be used to ensure the grain meets the exporter's or importer's official regulations for lack of infestation.

In some cases, the pre-shipment treatment is used to disinfest ship holds or other conveyances before placing grain or similar commodities in the ship hold, in order to prevent infestation from contaminated holds during shipment.

Pre-shipment treatments in general are aimed at a lower standard of pest control than quarantine. While quarantine treatments lead to a commodity free of regulated quarantine pests, pre-shipment only requires the consignment to be "*practically free*" of pests. This lower level of security gives some wider choice of alternatives, with reduced requirements for efficacy testing.

Alternatives to methyl bromide fumigation for pre-shipment of cereal grains, including rice, vary with situation, particularly the required speed of action. In some export situations, there is sufficient capacity at the port, to allow slower acting alternative treatments to be used easily, with treatment times of 7 days or more for full effectiveness.

In many export situations, a high throughput is required, where there is limited space at the port for treatments and as demurrage costs on waiting vessels is high. Typical turnaround times for methyl bromide for a shipment can be 24-48 hours, a time that has to be accommodated in the organisation of the export consignment under pre-shipment treatment.

Some importing countries may specify fumigation at point of export as a pre-shipment treatment, with indications as to what treatments are acceptable. In cases where methyl bromide is specified as one treatment, phosphine fumigation may be specified as an alternative. However, several countries specify use of methyl bromide as the only acceptable QPS treatment of imported grain from specified exporters

Phosphine fumigation is in widespread use for this purpose, for both bagged and bulk consignments. Transition to phosphine for the pre-shipment of grains has been driven largely by economic consideration. Increasing health regulations associated with avoiding worker exposure to methyl bromide are likely to further encourage use of alternatives.

Treatment of bulk or bagged grain in ships with phosphine after loading can replace some current pre-shipment uses of methyl bromide. However, this may be interpreted as falling outside 'pre-shipment' and may not meet regulatory requirements of some exporters and importers who require grain to be practically pest-free before loading. Phosphine treatments may be conducted at the dockside, in lighters or barges prior to loading a ship, or in the ship after loading and before sailing. In suitable ships, in-transit phosphine treatment gives an effective post-export treatment.

The International Maritime Organisation recommendations on safe use of pesticides in ships and shipping containers describe the safe use of both phosphine and methyl bromide at port and in-transit (IMO 2008ab). The Organisation specifically recommended that cargoes should not be fumigated in ships with methyl bromide prior to sailing due to the risks resulting from the difficulty in ventilating the cargo effectively (IMO 1996). As an alternative to methyl bromide, for safety and efficacy reasons, in-transit treatment with phosphine is restricted to specially-designed bulk carriers, tanker-type vessels and other ships where the holds are gastight or can be made so (Semple and Kirenga 1997). In addition, equipment must be installed to circulate the phosphine through the cargo mass (Watson *et al.* 1999). The circulation equipment ensures that the gas penetrates throughout the load and can be aired from the load prior to unloading. In-transit treatment of bulk grain is in widespread use, potentially avoiding the need for methyl bromide treatment prior to shipment where import and export regulations permit.

Recently for example, the Indonesian Applied Research Institute of Agricultural Quarantine (ARIAQ) has established phosphine fumigation protocols using ECO2FUME for QPS treatment of major commodities in the country such as rice and other stored grains, coffee, cacao, tobacco, pineapple, and mangosteen. Additional phosphine fumigation protocols are currently being developed for other commodities such as wood chips, cut flowers and other export fruits and vegetables. The Indonesian AQA is also working on bilateral agreement with importing countries in the adoption of ECO2FUME for QPS treatment (Tumambing, 2013). A comprehensive "Technical Manual for Liquid Phosphine (ECO2FUME)" in Bahasa Indonesia and English version was produced and later approved for implementation by the Indonesia AQA. The said technical manual will serve as a reference guide for all Indonesian fumigators involved in QPS treatment of different import and export commodities using ECO2FUME.

Controlled atmosphere technologies have some usage at present, but have potential for much more widespread adoption. The application of CA technique in e.g., Vietnam, is also certificated by the Plant Protection Department of Vietnam as a qualified treatment practice for phytosanitary objects. This certification allows users to control insects for import of phytosanitary objects, without using any toxic chemicals. Necessary documentation such as a Phytosanitary certificate to declare that the products have been inspected and/or tested and to state that the products are considered to be free of quarantine pests is provided, based on the treatment certificate of a CA treatment.

Direct application of pesticide to the grain will also will give pest-free grain to inspection standards, sometimes with a holding period before inspection to allow for action of the pesticide on the pests. Rapid acting pesticides for direct application include dichlorvos and cypermethrin. The use of methyl bromide alternatives is limited by various registration issues and also by market and end user requirements, some of which require 'residue-free' grain.

Sulfuryl fluoride fumigation is restricted by the availability and registration of the fumigant to only a few countries at this time. However, it is now used routinely as an alternative to methyl bromide for pre-shipment treatment of grain e.g., in Australia.

Although heat is technically feasible, its use is limited by the high cost of heat treatment facilities that are able to heat grain moving at fast handling speeds, such as when loading or discharging, compared to the costs of facilities to implement other alternatives. Small scale heat disinfestation facilities for bulk grain, operating at a relatively slow speed of tens of tonnes per hour throughput, are commercially available.

4.9.4. Alternatives for pre-plant soils use for propagative material and nursery uses

4.9.4.1. Treatment of soil with methyl bromide to control pest incursions

Pests that are accidentally introduced to an area where they are not known to occur is called an 'incursion'. When an incursion of a pest occurs, such as a soil pest, disease or weed, it is important to implement a control measure as soon as possible to prevent the pest spreading. During this time, the pest is under "*official control*" and it is considered a quarantine treatment. If the spread stays restricted, the pest may stay under official control until such time that the pest is eradicated which is the ultimate goal.

Methyl bromide has been selected for many years by phytosanitary organisations to treat incursions. Treatment of soil to eliminate officially-recognised quarantine pests, either in soil transported as a substrate or treated *in situ*, is consistent with the Montreal Protocol's definition of a QPS use. Examples include:

- Soil or substrate that is either imported or exported as a commodity (to grow plants in) was sometimes fumigated with methyl bromide as a quarantine measure in Malaysia[4]
- Soil *in situ* was fumigated for controlling and containing quarantine pest, such as the pale potato cyst nematode *Globodera pallida,* which is a quarantine pest in the United States. Occurrence is limited to the State of Idaho. The movement of plant materials from the State and designated quarantined areas within the State are restricted by State Regulations[5]. In 2007 and 2008, a total of 217 tonnes of methyl bromide were used to control incursions of the potato cyst nematode (TEAP 2009)
- Soil fumigated with methyl bromide in Australia prior to 2006 to control and eliminate branched broomrape, which is an exotic quarantine pest (parasitic plant) that has a limited distribution within the country.

If the pest/disease/weed spreads rapidly then it may lose its official control status. In that case methyl bromide use is no longer considered a quarantine treatment. Methyl bromide can still be used providing an exemption is granted for this use under the CUE process e.g., Israel use for broomrape prior to 2010. However, the CUE approval takes longer than one year during which time the pest can spread, and therefore methyl bromide is not an ideal solution for the initial control of a pest incursion.

Alternatives are being sought to replace the use of methyl bromide where it is known to not be fully effective in controlling pests or in cases where there are restrictions on its use. MBTOC is unaware of studies which report directly on the relative efficacy of alternatives to methyl bromide to manage pest incursions. However, fumigants

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4 TEAp, 2009 (QPSTF Report) and MBTOC survey sof MB uses 2009 qnd 2010 Some of Malaysia's total QPS consumption of 5.05 tonnes in 2007 and 0.5 tonnes in 2009 was reported to have been used for treatment of soil as a substrate

5 Federal Register Vol 73 No. 177, Sept 11, 2008; USDA 2007. Regulations 301.86 to 301.89

used to the disinfest soil as a result of work in the non-QPS sector can provide guidance on the suitability of alternatives for controlling pest incursions (See chapter 5). Methyl bromide was not totally effective in controlling branched broomrape incursions in Australia. Alternatives to methyl bromide are now used to manage the incursions (Faithful and Maclaren, 2004). In the US, fumigants designated for use for preventing incursions are permitted to be used at rates higher than those specified on the label. This designation opens up the opportunity for the temporary use of non-MB soil fumigants to control pest incursions.

4.9.4.2. Treatment of soil with methyl bromide to control pests in propagated plants

MB can also be used to control pests, diseases and weeds in soil to meet official certification standards. Treatments of soil-in-situ against endemic pests on nursery plants to meet certification standards was about 25% of the QPS consumption reported by non-Article 5 Parties (TEAP 2010). The USA is the only Party that classifies pre-plant soil fum,igation with methyl bromide for certification as a QPS use. All other Non-Article 5 Parties classify such treatments as normal soil use that would require an annual CUE approval, if alternatives to methyl bromide are not available.

The treatments with methyl bromide in the US target only nematodes that are found in strawberry nursery runners, forest nurseries, turf grass, bulbs, ornamental plant nurseries and seed potatoes. The US maintains a QPS exemption for use of MB for these uses complies with 'Federal Register Rule' (FR68). This Rule covers only '*plants for planting'* that are '*moved from one distinct locality to another*' and for '*official quarantine requirements specifying that the underground portions of the propagative material must be free from quarantine pests*'. The Rule only applies to propagative material to meet official quarantine requirements of the destination to which such material in transported. However, the quarantine pests present at the source must not be present at the destination, in order to be consistent with the intent of the FAO definition of 'Quarantine' and the definition used in the Montreal Protocol.

The limited data available (Horner 1999, De Cal *et al*. 2004, Mann *et al*. 2005) indicates that methyl bromide fumigation of the soil and other fumigant alternatives cannot guarantee the soil is entirely free of pathogens, especially fungal pathogens**..** In addition, soil disinfestation with methyl bromide, whilst often being an effective tool for minimising disease levels on nursery stock, does not guarantee a reduction in disease levels to zero, but only to a low and undefined level.

Although QPS methyl bromide has not been reported for fungal pathogen control, the prospects of control to the standard required for certification appear limited. Horner (1999) showed that root material infested with *Phytophthora fragariae* could still survive MB:Pic/70:30 fumigation when placed at depths of 12 to 30cm in soil and, moreover, that these infested roots could still cause both root and crown root symptoms. They also showed that alternative fumigants, e.g. chloropicrin or 1,3-D/Pic produced similar results to the MB/Pic treatments. De Cal *et al.* (2004) isolated *P. cactorum* (in up to 7% of plants), *Fusarium* (3%), *Pythium* (2.5%), *Verticillium* (0.2%) and *Colletotrichum* (0.2%) from strawberry runners produced in soils disinfested with methyl bromide. In these examples, disease levels were higher than would normally be expected to meet certification standards for disease tolerance (usually <1% of plants affected).

Similarly, Mann *et al*. (2005) showed that hot-gas MB (100%, 60 g m^{-2}) did not eradicate consistently buried inoculum of *Fusarium oxysporum, Rhizoctonia solani, Rhizoctonia fragariae* or *Sclerotium rolfsii* placed at depths of 10, 20 and 40cm in a clay-loam soil, particularly at soil depths of 40 cm. Another study showed that injected MB:Pic (30:70, 50 g m^{-2}) did not eradicate buried inoculum of *Phytophthora cactorum, F. oxysporum, R. solani, R. fragariae* or *S. rolfsii.* Survival was generally low, mostly at depths of 20 and 40 cm in soil and was higher when samples were taken further away from the injection point for methyl bromide.

Production of high health propagative materials remains a significant challenge in some sectors (ie strawberry runners) as Parties transition away from MB (Zasada *et. al*., 2010). Alternatives, particularly combinations of existing alternatives including the 3 way system (1,3-D, Pic and metham), and 1,3-D/Pic are being widely adopted to replace use of MB for critical uses. Some have been used to replace methyl bromide for the production of certified plant nursery material. MBTOC notes that many countries have phased out methyl bromide and alternatives are now used for production of certified plants or plants required to meet stringent high health standards. The EU phased out MB in nursery production between 1992 and 2007 (EC Management Strategy, 2009). Chemical alternatives in commercial use for this purpose include dazomet, metham sodium, and 1,3-D (with restrictions as stated in Chapter 5 of this report). In A5 countries, certified plant materials are produced without MB; for example, substrates are used for certified citrus and banana propagative materials in Brazil (Ghini, pers. comm., 2014); grape, pear, apple, and citrus propagative materials are produced in Argentina without MB (Valeiro, pers. comm., 2014).

Japan phased out MB in nurseries in 2005. Alternatives in commercial use include dazomet, chloropicrin, 1,3-D, and MITC (Tateya pers. comm., 2010). A recent publication gives an excellent overview of the situation for the strawberry nursery industry around the world (Lopez- Aranda, 2012).

The use of substrates also offers another alternative method to methyl bromide which avoids the need for soil fumigation with any chemical to grow crops, however it is often too expensive. Several industries in some countries (ornamentals, cucurbits, tomatoes, strawberries) have nevertheless adopted soilless production where economically feasible (i.e. can include only certain stages of the propagation system), to avoid the need to grow crops in soils that can harbour endemic and exotic pathogens and pests.

4.9.5. Alternatives for fresh fruit and vegetables

Although the vast majority of horticultural products globally are harvested and placed on the market without any postharvest treatment, some of the trade in horticultural products enters the market only after a treatment has been carried out on the harvested product that aims to kill any pests that are of concern. Such treatments can be important for reducing the risk of accidentally transferring pests present in the export country but not in the importing country. These treatments may be applied either pre-shipment, in-transit or on arrival depending on the phytosanitary requirements of the importing country.

Postharvest insect control treatments applied to horticultural commodities may include physical treatments (such as cold, heat, controlled/modified atmospheres, removal, irradiation, radio/microwave frequencies, pressure/vacuum), fumigation treatments with either Generally Recognised As Safe (GRAS) compounds (i.e. ozone, ethyl formate), or higher risk fumigants (i.e. methyl bromide, phosphine, sulphuryl fluoride, carbonyl sulphide, cyanogen) or insecticidal dips. Some postharvest practices currently used, such as coolstorage, can be utilised as a disinfestation treatment (or part thereof) if efficacy can be demonstrated. In addition, computing power and visual and spectral systems have now reached the point where insects can be detected "in line" (during packing), and thus fruits with insects might be excluded during packing.

MBTOC (2002) recorded more than 300 alternative quarantine treatments for perishable commodities that had been approved by a National Plant Protection Organisation (national quarantine authorities). Ensuing MBTOC Assessment Reports (2007, 2011) also provide ample information in this respect.

Approved alternatives, which are presently in use include cold treatments, various types of heat treatments, heat + controlled atmospheres, pesticide dips or sprays, wax coating, pest removal (e.g. by brushing), alternative fumigants, irradiation, crop production in areas free from quarantine pests, the systems approach, and inspection procedures.

The type of alternative treatment to methyl bromide that can be applied to kill insects on horticultural products tends to be specific to individual crops, cultivars, pests, markets and even growing regions. Alternatives to methyl bromide should be cost-effective, practical to apply within the logistics chain, and sufficiently effective against a wide range of insects.

New solutions are also being increasingly targeted to be "soft" solutions that leave no residues, and in some cases even reduce agrichemical residues that were applied pre-harvest.
Restrictions on residues are increasing in many markets and there has been renewed interest in utilising postharvest disinfestation treatments that do not leave residues, to control pests that have previously been controlled by residue-contributing preharvest measures, and even to decrease residues after harvest (e.g. water blasting or hot water treatments). Non-chemical disinfestation may become a marketing advantage (healthy fruit) and a valuable alternative to methyl bromide (Chevin *et al.* 2000).

Certain quarantine treatment technologies such as irradiation are not universally accepted, which slows their adoption. Other treatments such as heat or cold can be faster to implement since they are not chemicals that require registration. Area-wide pest management programs lower pest levels before harvest and improve the quarantine security provided by any postharvest treatments. These lead to "Systems Approaches" which capitalize on cumulative pest mortality from multiple control components to achieve quarantine security in an exported commodity. Standardized phytosanitary measures and research protocols are needed to improve the flow of information when countries propose to trade in a regulated commodity (Follett and Neven 2006).

4.9.5.1. Cold treatment

Cold storage is used for the majority of fresh produce to extend its postharvest life and can effectively control many pest species. An advantage of cold treatments is that they can be applied in transit. However, evidence of compliance with insecticidal, in-transit requirements of the importing country can be difficult to produce for compliance purposes. Cold treatments are generally not suitable for tropical and subtropical fruit as they are more susceptible to chilling injury. However, some cold-sensitive commodities can be preconditioned at temperatures near to the chilling threshold to enhance tolerance to a subsequent disinfestation cold storage treatment.

In general, the order of susceptibility for some market access pests on produce from most susceptible to most tolerant (indication of the number of days required for ~99% mortality at 0^oC) is: mealybug (18-30) < lightbrown apple moth (34-76) < leafrollers (46) = codling moth (66-152) < mites (26% @ 90 days). It is important to note that effective lethal times are generally more for pests on fruit than for the same pest/life stage off fruit. Cold storage is generally a long treatment and depends on the susceptibility of the species and life stage to low temperatures. Some fruit can be stored for many weeks before export.

Cold treatment is a long used MB alternative for importation of citrus fruit into the US from areas of the world indigenous for quarantined species of fruit flies. Because of discovery of surviving fruit fly larva in cold treated fruit, the effectiveness of this protocol was put in doubt. USDA scientists, working with scientists from South Africa, Argentina and Kenya are revising the protocols to ensure its continued use as a MB alternative.

Cold treatments for *Bactrocera tryoni* on oranges (*Citrus sinensis*), on tangors (*Citrus reticulata* × *C. sinensis*), on lemons (*Citrus limon*) in the process for approval. The TPPT accepted the schedules and recommended to the IPPC Standards Committee for adoption by the CPM to be included in ISPM 28 (IPPC, 2011).

4.9.5.2. Heat treatments

Heat is generally acceptable from the environmental standpoint but is energy-intensive and could be questioned with respect to CO_2 emissions. Applied treatments range from 40 to 50^oC for minutes to hours. Heat treatments are usually required to bring the core temperature of the largest fruit in the coolest part of the treatment chamber to the specified temperature and hold it for the required time. The temperature, duration and application method must be precise and uniform to kill pests without damaging the commodity.

Heat treatment is suitable for controlling internal and external pests, as the treatment penetrates in to the commodity. Heat treatments can be applied as hot water or hot air. Hot air treatments can be applied as a high relative humidity ("vapour heat") or low relative humidity heat treatment (HTFA).

For more susceptible commodities, conditioning treatments prior to heat treatments can increase their tolerance to subsequent heat treatment (Hara, 1977). However, any conditioning treatment needs to be thoroughly investigated, as the tolerance of the pest to heat treatment may also be enhanced thereby reducing its usefulness as a disinfestation treatment.

Most of the hot air disinfestation research carried out use a high temperature forced air (HTFA) system (low relative humidity) system that overcomes the problem of water condensing on the surface causing commodity damage, which can occur when the vapour heat treatment is used. Many heat treatments have been approved by regulatory authorities for disinfesting fruit flies from tropical and subtropical fruit products. The cost of heat treatments has been reported to be 6-7 times more than that of methyl bromide fumigation (USEPA, 1996). HTFA treatments have been developed and are operating as quarantine pre-shipment treatments in the Pacific region (Williamson and Williamson, 2003; Waddell *et al.,* 2004), the US (USDA, 2001), Mexico (Shellie and Mangan, 1995) and others.

Vapour heat treatment uses air saturated with water vapour whereby heat is transferred by the condensation of water vapour on the cooler fruit surface. It is mainly used for the disinfestation of fruit flies on subtropical fruit, with a specification for most products is 44.5oC for 8.75 hours and then immediately followed by cooling. Commercial facilities operate in many countries including Australia, the USA, Thailand, Taiwan, and the Philippines. The USDA has approved vapour heat treatment for bell pepper, some citrus, eggplant, mango, papaya, pineapple, squash, tomato and zucchini. Vapour heat treatment for *Bactrocera tryoni* on mangoes (*Mangifera indica*) in the process for approval. The TPPT (Technical panel on Phytosanitary Treatments) accepted the schedule and recommended the IPPC Standards Committee to send it for member consultation (IPPC, 2014).

High temperature can also be combined with controlled atmospheres to decrease the severity of the treatment (time or temperature) while maintaining high pest mortalities. The relative mortality responses of leafrollers to a wide range of HTCA treatments have been identified (Whiting, 1999). A controlled atmosphere/temperature treatments system (CATTS) has been effective in disinfesting cherries from codling moth (Nevin and Drake, 2000).

Hot water treatment offers an additional option for heat treatment and involves immersing a batch of fruit in heated water for a specified time at a specified temperature. Short but high temperature hot water treatments were shown to be an effective non-chemical method for controlling fungal pathogens in citrus without human health risks associated with the chemical fungicides. The research was carried out because of increasing concern with the use of such fungicides, particularly in the diets of children, as well as concerns with widespread occurrence of fungicide-resistance isolates, with environmental problems associated with the disposal of water used in packing operations, and with the limited number of fungicides available to control rots in citrus (Irtwange 2006). The researchers postulated that the same temperatures that were used to control the fungi may also control insects on the surface of the citrus. Longer treatments are required for internal pests such as fruit fly, to heat the whole fruit but such longer duration treatments are likely to damage many crops. Generally, hot water treatments are more effective at the same temperature than hot air treatments, because of faster heat transfer in water and the more uniform heating of the fruit by use of high water flow, and therefore hot water generally costs less to apply

4.9.5.3. Controlled and modified atmospheres (CA, MA)

CA treatments at ambient have been used for many years to prolong the storage life of many commodities and to control pests, in particular in grains and nut crops. Research has demonstrated its efficacy against pests for fresh commodities. In general, the most effective CAs at ambient were below 1% O_2 and above 20% CO_2 for insect control.

Most insecticidal treatments using CA require long exposures, ie, six days were required to control flower thrips (*Thrips obscuratus*) on kiwifruit flowers at 2% O_2, 18% CO_2, 20°C (Potter *et.al,* 1994) while carbon dioxide concentrations of >30% at 20°C were shown to kill onion thrips (*Thrips tabaci*) on onions after at least 24 hours of fumigation. These long treatment times may not be acceptable for some markets as they miss the period of highest market prices. In addition, prolonged exposure to low O_2 and/or high CO_2 has a detrimental effect on some fresh fruits.

Cold storage can be applied in combination low oxygen and/or high carbon dioxide atmospheres and this is referred to as controlled atmosphere (CA) cold storage. The ability of cold storage to control pests can be improved when cold storage is combined with controlled atmospheres. The more cold tolerant species include codling moth, mites, apple leafcurling midge. When cold storage is combined with controlled atmosphere, the time to cause high pest mortality can be further reduced (i.e. leafrollers – Whiting *et al.* 2000) in most cases, but not always (i.e. scale insects, Whiting *et al.* 2003).

Navarro *et al.,* (1999) showed that the addition of CO_2 halved the amount of MB required to kill larvae when compared with MB without CO_2. The amount of methyl bromide could be reduced still further at elevated temperatures.

Hot, forced, moist air with a linear heating rate of 12°C/h to a final chamber temperature of 46°C under a 1% oxygen and 15% carbon dioxide environment has been successfully used to control codling moth, *Cydia pomonella* (L.), and oriental fruit moth, *Grapholita molesta*, a serious pests of apples for whisch strict quarantine restrictions are in place in some countries (Neven and Rehfield-Ray (2006).

Non-chemical quarantine treatments, using a combination of short duration high temperatures under low oxygen, elevated carbon dioxide atmospheric environment were also developed by Neven and Rehfield-Ray (2006) to control western cherry fruit fly, *Rhagoletis indifferens* in sweet cherries

4.9.5.4. Removal

There is a range of techniques that can be used to remove insects from fruits physically. A significant advantage of treatments that remove insects compared with those that simply kill insects is that absence of insects on arrival in overseas markets means that the product line is much more likely to pass official phytosanitary inspection.

Use of rotating brushes during packing (generally prior to quality checking and grading) is a common practice in most fruit crops. This is carried out either on dry brushes or with lightly wetted brushes. Such treatments remove dirt and other material from fruit, and in doing so they also remove exposed pests such as thrips, mites, beetles and Collembola. However, they will not remove insects and mites that are well protected by either their structure e.g. scale insects or insects within cocoons fastened to the surface, or because they are protected by coverings or location in crevices or structures of the fruit e.g. under calyx.

Removal by water blasting (or high pressure water washing) is also in use. This can be done for longer durations (10-20 seconds) over rotating brushes, or for very short times without brushes.

Moderate pressure / high volume water systems were developed successfully for citrus to dislodge scale. These washers been used in a number of countries including the USA, Israel, New Zealand and South Africa, also for other fruits such as apples. Although water blasting is generally carried out using cold water, the value of killing and removing mould spores and insects using hot water and additives has been examined in the Western US (Bai *et al., 2006;* Hansen *et al*, 2006; Neven *et al.,* 2006; Spotts *et al,* 2006).

A high-pressure apple washer was developed in New Zealand that oriented fruit and sprayed them with a much shorter (generally 0.5 to 1 second) higher pressure water treatment. In Australia, A higher pressure low volume treatment has proved to be successful in avocado (Jamieson, 2005), and water blasting is now a requirement for avocados entering the USA. Water blasting is also very effective in removing pine pollen (*Pinus radiata*) from the base of fruit, and spray residues.

4.9.5.5. Ionising irradiation

Various forms of ionizing irradiation have been investigated as disinfestation treatments. Including as alternatives to MB The three major forms are gamma irradiation, electron beam, and x-ray. Gamma irradiation is generated from radioactive isotopes, which causes public concern with the safety of isotope transport, long-term storage and facility location. Electron beam irradiation does not use radioactive material, and therefore does not have the same public concerns. Gamma irradiators have better penetration and can treat packaged or bulk products, while electron beam accelerators more effectively treat products in thin layers (2-5 cm thickness). X-ray irradiation has better penetration than electron beam. However, the technology using X-rays is a recent development for disinfestation and published reports more limited than for research based on gamma and electron beam.

Generally, irradiation doses from 0.05 to 0.2 kGy are sufficient for quarantine security, but the exact dose varies with the insect being targeted. The USDA-accepted treatment dose for fruit flies is 75-150 Gy. However, other insects, such as moths, require a dose of ~250 Gy At these doses the insects are not necessarily killed but will not continue development. In these cases, evidence of exposure to irradiation is required to satisfy phytosanitary inspectors that the insects although alive are sterile and present no biological risk.

An advantage of irradiation compared with some other non-fumigation methods is that the treatment is fast, residue-free and fruit can be treated in the final packaging. Three challenges exist with using irradiation as a quarantine treatment. Firstly, compared with other treatment options the capital costs of irradiation are high, which means treatments must be made in a few central locations. Secondly, irradiation can render the pest stages sterile, rather than dead, leaving the government or quarantine inspector uncertain as to whether the insects were exposed to irradiation, whether all the insects were treated, or whether the pest entered the commodity following irradiation. Thirdly, irradiation does not have regulatory approval as a food treatment in all markets and has poor consumer acceptance in some, although this is changing and may be less of an issue in the future. In the past, consumers have been concerned with food safety issues relating to irradiated products.

Nevertheless, the use of irradiation as a phytosanitary treatment has increased s, with an undetermined part of this volume directly replacing methyl bromide fumigation. In 2013, about 5,800 tonnes of fresh fruit were irradiated for import into the US. This is a dramatic increase of 6,500% with respect to 2007 (Jeffers, 2014). Most PPQ treatments occur in the exporting country (and are thus pre-cleared), for example Mexico, South Africa, Thailand and Vietnam (Jeffers, 2014).

Other products traded with an irradiation treatment include purple sweet potatoes from Hawaii, mangoes from India; guava, mangoes and papayas from Mexico; grapes from South Africa; lychees, mangosteen and rambutan from Thailand; and Dragon fruit from Vietnam. Irradiation treatments have recently shown to provide sufficient quarantine security against the mango pulp weevil, *Sternochetus frigidus,* an important quarantine pest preventing the export of mangoes from the Philippines to the United States and other countries (Obra *et al*, 2014). Additionally, about 175 million lbs of spices are irradiated each year in the US as a treatment against microbial contamination.

Irradiation treatment for mealybugs (Pseudococcidae) for all fruits and vegetables in the process for approval. The TPPT accepted the schedule and recommended to the IPPC Standards Committee for adoption by the CPM to be included in ISPM 28 (IPPC, 2011, 2014).

4.9.5.6. Radio frequencies and microwaves

Radio-frequency (RF) and microwave energy are sources of heat that involve the application of electromagnetic energy at 10-30,000 MHz. Because of the congested bands of radio-frequency and microwaves already being used for communication purposes, regulatory bodies have allocated five frequencies for industrial, scientific and medical applications: 13.56, 27.12, 40.68 MHz in the RF range and 915 and 2,450 MHz in the microwave range. It is important to develop effective means to deliver thermal energy uniformly to every part of the fruit where insect pests may reside, to shorten treatment time and minimize thermal impacts on the fruit quality. RF heating has the advantage of fast core heating of fruits because of direct interaction between the RF energy and the fruit tissue to raise the centre temperature quickly, especially for large fruits. At some wavelengths, insects can be selectively heated without adversely heating the fruit (Schneider *et al.,* 2003).

RF and microwave treatments to control pests on various commodities have mainly focused on control of beetles and moth larvae (Lagunas-Solar *et al, 2007;* Birla *et al,* 2008a). For internal pests, RF has been used in combination with water immersion to obtain uniform temperature increases in both the core and surface of the commodity (Tiwari, 2008).

The prospects of using radiation energy sources for post-harvest pest control has received increasing attention in recent years, particularly in the area of microwave (Purohit *et al*., 2013; Manickavasagan *et al*., 2013) or radio wave frequencies (Jiao *et al*., 2012; Wang et al., 2013). The use of ionizing radiation in this field has recently been reviewed by Hallman (2013).

4.9.5.7. Pressure treatments

Pressure techniques (mainly below barometric pressure – vacuum) have been investigated as a means for pest control on commodities for many years.

A pressure-based method for rapid and effective insect and mite control that combines pressure, controlled atmosphere and volatiles, was developed by the University of California and Plant & Food Research in New Zealand. The method is known as 'metabolic stress disinfection and disinfestation' (MSDD) and combines physical and volatile treatments to disinfest plant products. It has been shown to be a rapid and effective method for controlling microbial and arthropod pests, applicable to a range of commodities (Lagunas-Solar, 2006).

4.9.5.8. Alternative Fumigation Treatments

Fumigation is a widely used treatment employed to eliminate pests from a range of commodities including fruits and vegetables. During fumigation, a chemical with a high vapour pressure is introduced into a closed space and maintained at a certain level for a specified minimum time.

A 'Generally Recognised As Safe' (GRAS) status for a compound is determined by the US Food and Drug Administration. GRAS compounds are considered safe for use with human food (Anon, 1993a). The advantage of treatments utilising GRAS compounds is that they are already accepted by the USDA-APHIS-PPQ after a series of strict criteria have been satisfied. GRAS substances may therefore be excluded from mandatory premarket approval by the United States Food and Drug Administration when used on produce to control pests.

4.9.5.8.1. Ethyl formate

Ethyl formate is a plant volatile. It is classified as a GRAS compound and therefore considered safe for use in conjunction with food (Anon, 1993a). Ethyl formate is flammable and explosive when mixed with air at concentrations required to kill pests, but formulations in CO_2 reduce this risk significantly. Ethyl formate is currently registered in Australia, Switzerland, Italy, United Kingdom, United States, Germany, Canada and New Zealand. VAPORMATE™ (16.7 wt% ethyl formate dissolved in liquid CO_2) is registered and used through other regions.

Vapormate™ is being increasingly used for disinfestation of fresh fruit and other perishables in situations where MB could be used, particularly where target pests are on the outside of the treated commodity. Vapormate is a rapid acting, non-residual post-harvest fumigant for the control of insects (adults, juveniles and eggs) in stored grain, oilseeds, dried fruit, nuts, fresh produce (e.g. bananas, blueberries) and cut-flowers, enclosed food containers and food processing equipment (Finkelman *et al*., 2012). It is also a naturally occurring compound in the environment and present in some plants/food products.

As alternative to MB for the disinfestation of nitidulid beetles (the proportion of insects found outside the feeding sites and nitidulid beetles from artificial feeding sites under laboratory conditions), the effect of various dosages of Vapormate was tested at 30°C and after a fixed exposure time of 12 h. Exposure of artificially infested feeding sites (larvae of *Carpophilus* spp.) to a concentration of 280 g m^{-3} of Vapormate caused 69.3% disinfestation and 79.9% mortality, 350 g m^{-3} resulted in 72.7% disinfestation and 98.8% mortality, and the optimal results were obtained at 420 g m^{-3} that caused 69.6% disinfestations and 100% mortality. Commercial pilot-plant tests were carried out by applying 420 g m^{-3} Vapormate for 12 h within a 9 m^3 flexible liner of gas-impervious laminate (polypropylene/ aluminum/ polyethylene) to cover crates containing infested dates. Disinfestation (removal of larvae from infested dates) was tested on naturally infested dates that resulted in average 100% disinfestation and 95% mortality, while with the artificially infested dates, disinfestation was 97% and mortality 96%. In a second series of tests, a commercial rigid fumigation chamber of 95.6 m^3 was used. After 12 h of exposure, 100% mortality was recorded in all date samples.

Mitcham *et al*., (2011) and Pupin *et al*., (2011) reported mortality test with Vapormate. Bean thrips are a quarantine pest of navel oranges in some countries. The authors showed that fumigation for one hour of thrip-infested navel oranges at 5˚C with 31 mg/l ethyl formate gave a 100% kill of over 35,000 thrips treated in the test. The fumigation had no deleterious effect on the navel orange quality. Fumigation of some varieties of table grapes with Vapormate at a concentration effective for quarantine control against the light brown apple moth, did however reduce the quality of export quality grapes. Additional testing is in progress to determine whether this damage could be minimized by changing the fumigation parameters.

Vapormate use is increasing and has been successfully applied for controlling surface pests on export blueberries in New Zealand where some 120 consignments have been treated in shelf ready packaging. The consignments have passed phytosanitary inspection with no live pests found immediately after treatment (Glassey, pers. comm., 2014). This contrasts with MB fumigation where some pests can take some days to die at rates suitable for the fruit. Apples infested with eucalyptus weevil have been successfully treated in four large field trials with ethyl formate at 50-55g m^{-3} for 24 hours at 4-8°C with no harm to the apples (Agarwal *et al*., 2012). Vapormate also successfully controlled overwintering spotted spider mites *Tetranychus urticae*, on persimmons within 6 h at 5°C with a ct products of 147.98 g h m^{-3} and the grape-myrtle scale *Asiacornoccus kaki* deleterious with 41.12 g h m^{-3} to result in 99% mortality (Cho *et al*., 2012).

In Japan, mortality tests are carried out with a mixture of ethyl formate gas and carbon dioxide for controlling the leafminers *Liriomyza sativae and L. trifolii*, spider mites *Tetranychus cinnabarinus* and *T. Kanzawai*, scales and mealybugs. All spider mites except for diapause adults of *T. kanzawai* were killed with the gas mixture at a dosage rate of 250 g m^{-3}, and diapause adults were killed at 350 g m^{-3}. Control of pupal stages of both leaf miners was less complete (Yamada *et al*., 2012).

Five species of scales (*Diaspis boisduvalii, Aonidiella auranti*, and *Coccus hesperidum*) and mealybugs (*Planococcus citri* and *Dysimicoccus brevipes*) were fumigated with a gas mixture of ethyl formate and carbon dioxide using the same formulation as Vapormate. All tested developmental stages of *D. boisduvalii*, *A. auranti,* and *C. hesperidum* were completely killed at a fumigation dosage of 150 g m^{-3} after treatment for 3 h at 15°C. Crawler, nymph, and adult *D. brevipes* were more tolerant than *P. citri*; however, these stages of both mealybugs were completely killed (100 %) at dosages of 100 g m^{-3} of the gas mixture. Among the five species tested, the least susceptible stage were the eggs of *P. citri*. They were killed (100%) with the described gas mixture with 350 g m^{-3} dosage rate under vacuum (<18□22 kPa) (Misumi *et al*., 2013a).

Possible quality changes in banana, pineapple, strawberry, grapefruits, Satsuma mandarin, squash, string bean, parsley and broccoli are also investigated in Japan. It has been found that the gas mixture of ethyl formate and carbon dioxide is an effective quarantine treatment for fruits that could be adopted in the future. Some degree of damage has been observed on leafy vegetables, but changes in flavour were observed in parsley (Misumi et al., 2013b).

The residues from ethyl formate quickly break down to levels occurring naturally in food and in the environment. Ethyl formate is effective at low temperatures and therefore does not reduce the shelf life of products. Its activity is strongly synergised by CO_2. While the price per kilo is comparable to methyl bromide it is more expensive to be successfully applied due to the higher application rate, but with lower phytotoxicity and immediate death of pests. Thalaviassundaram and Roynon (2012) found that ethyl formate penetrated through the commercial cardboard and plastic wrapping of sultanas.

Vapormate is now registered in South Korea and used as a quarantine treatment for fumigating some imported fruits including bananas (Lee *et al*., 2009). This fumigant is registered in Australia and New Zealand for a range of postharvest durable commodities including grains, but not yet as a quarantine treatment. Vapormate is registered and widely adopted for disinfestation of dates in Israel for use by the date industry as an alternative to MB (Navarro, 2006; Finkleman *et al*, 2010). According to a new Tunisian law, MB is now banned for use in all newly built packing houses (Dhouibi personal communication). Registration of Vapormate (ethyl formate+CO_2) for dates is under way in Tunisia (Dhouibi, 2013). Registration is also progressing in South East Asia, South Africa, the USA. The BOC South Pacific Company is continuing with industry market acceptance tests (Linde 2013).

4.9.5.8.2. Ozone

Ozone (O_3) is a naturally occurring compound that provides protection from the negative effects of ultraviolet light (UV). It is a colourless or bluish gas, heavier than air with a characteristic odour of electrical sparks. It can be generated by electrical discharges in air, and is currently used in the medical industry to disinfect medical equipment of micro-organisms and viruses. It is also used for reducing colour or odour and for removing taste, colour and environmental pollutants in industrial applications (Kim *et al,* 1999).

Ozone is classified as a GRAS compound and recently there have been increased efforts to develop and use ozone as a postharvest disinfestation tool in the USA. Recently, small, energy-efficient high-output portable ozone generators with ducted outputs have been commercially developed, generating sufficient concentration and volume to treat large volumes such as sea containers. Such units have the potential to provide an overnight treatment for a container while consuming a modest amount of electricity.

Ozone has the potential to cause damage to fresh produce and for this reason, concentrations of less than 50 ppm should be investigated. Ozone may need to be used in combination with cold storage if treatment times exceed eight hours. Reduced airflow is thought to severely decrease ozone efficacy. Humidity may also play a role in ozone efficacy. Ozone was six times more toxic at high than low relative humidity (Margosan and Smilanick, 2002).

4.9.5.8.3. Essential oils and volatile organic compounds

The fumigant activity of a large number of essential oils and essential oil components extracted from aromatic plants was evaluated on cut flower quarantine pests *Bemisia tabaci*, *Frankliniella occidentalis* and *Liriomyza huidobrensis* (Kostyukovsky *et al.* 2002). The most active compound had similar insecticidal qualities as methyl bromide against major insect pests of dry stored food. A concentration of 10 and 20 g/m3 and exposure time of 2 and 4 h, respectively, were sufficient to obtain 100% mortality of adult *B. tabaci* and *F. occidentalis*. A 50-60 g/m3 concentration for 2 h killed *L. huidobrensis* larvae.

Lacey *et al.* (2009) tested the effects of volatile organic compounds (VOCs) emitted by the endophytic fungus *Muscodor albus* on codling moth adults, neonate larvae, larvae in infested apples, and diapausing cocooned larvae in simulated storage conditions. Although adjustments are still needed with respect to exposure times and dosages, data on treatment of several stages of codling moth with *M. albus* VOCs indicate that the fungus could provide an alternative to broad spectrum chemical fumigants for codling moth control in storage and contribute to the systems approach to achieve quarantine security of exported apples.

4.9.5.9. Non GRAS fumigants

4.9.5.9.1. Phosphine

Most reports concerning the efficacy of phosphine fumigation for fruits and vegetables as well as cut flowers have used the metallic phosphide pellets. Fumigation with 0.5 – 4.5 g/m^3 phosphine (from metallic pellets) for 12-96 h at ambient temperatures can be effective against a wide range of insects The efficacy of phosphine applied as metallic pellets is reduced at lower temperatures and therefore its use below 10°C is not recommended. However, pure phosphine can be used at cool storage temperatures and be effective at concentrations that do not damage fresh produce.

In cut flowers, a dosage of 0.3 g/m3 phosphine for 4.5 h gave complete mortality of *Myzus persicae* and some mortality of larvae of *Strepsicrates ejectana*. Fumigation for 6 h with 1.4 g phosphine/m3 killed all pupae and most larvae of *S. ejectana*. Most of 19 species of cut flowers showed no sign of damage either immediately after fumigation or 7 days later. Williams *et al.* (2000) reported that the phosphine cylinder gas formulation $ECO_2FUME^{®}$ (phosphine with CO_2 as a carrier gas) was recently registered for a 15-h treatment of cut flowers. Very recently, Zhang *et al* (2015) reported that phosphine with or without CO_2 can achieve 100% mortality of Western flower thrips, *Frankliniella occidentalis*, an insect species which is widely distributed in China but limits exports of cut flowers as it is listed as a quarantine pest in some importing countries. The treatment had no adverse effects on vase life and damage indices of two oriental lily cultivars at 1.66mgL−1 PH3 and 12% CO2 for 16 h, and at 2.29mgL−1 PH3 without CO2 gas for 2 d at 5 ◦C.

Trials have indicated that phosphine fumigation usually resulted in satisfactory mortality of insects, but the quality of treated fruit could be reduced either because of the presence of ammonia in the phosphine (phytotoxic) or the relatively high fumigation temperature of over 15°C (Horn and Horn, 2004). In response to the problems encountered with fumigation using metallic phosphine, two types of cylinder phosphine gases that do not contain ammonia have been developed and commercialised by Cytec Industries Inc (2005).

$ECO_2FUME^{®}$ is a cylinder gas mixture of 2% phosphine and 98% CO_2. Phosphine is the active ingredient and carbon dioxide is used as a propellant and flame inhibitor. The gas mixture can be directly released into storage for fumigation. Fumigation using ECO_2FUME is safe and convenient (Cytec Industries Inc), but it could be considered expensive as it contains only 2% phosphine. $VAPORPH_3OS^{®}$ is a cylinder gas of 100% pure phosphine designed for use in conjunction with Cytec-approved blending equipment (i.e. The Horn Diluphos System) to dilute pure phosphine safely with air, therefore greatly reducing the cost of fumigation. The Horn Diluphos System (HDS) invented by Fosfoquim S.A., Chile, is an automated system that allows the direct dilution of pure phosphine (i.e. $VAPORPH_3OS^{®}$ from Cytec) with air to below the combustion limit. This allows the injection of a phosphine–air mixture into an enclosed space to fumigate with concentrations up to 10,000 ppm phosphine without risk of ignition (Horn *et al,* 2003). Application of HDS for fumigation of fresh fruits and vegetables in cooled fumigation chambers, cooling chambers or controlled atmosphere chambers at low temperatures between -1.5 and 15°C has been patented (United States Application 20050265892; Hort *et al*, 2005).

Trials conducted on the fruit fumigation showed that cylinderised phosphine can effectively kill all stages of insects using 1400 ppm at 0-6°C in 48-72 hours and a residue level below the maximum residue limit of 0.01 mg/kg (Cavisin *et al.* 2006). For treatment of exported cut flower and foliage in New Zealand, a shorter fumigation time of 4 hours is in commercial use with $ECO_2FUME^{®}$ under vacuum conditions.

Magnesium phosphide pallets, applied inside a chamber with the aid of a Speedbox (Detia-Degesch) to ensure rapid and uniform fumigant delivery, was found effective for controlling *Anastrepha fraterculus* fruit flies in feijoa (*Acca sellawiana)* in Colombia (Rodríguez *et al*, 2010), as well as thrips and aphids potentially associated with cut basil (*Ocymum* sp) without damaging these fresh products.

Pure phosphine has been used in Chile for the last ten years to fumigate apples, plums, peaches, citrus, pears, grapes, kiwifruit, cherry, nectarine, persimmons, avocados, quince and apricots. The HDS/VAPORPH$_3$OS technology was reported to be effective in controlling obscure mealybug (*Pseudococcus viburni*); codling moth (*Cydia pomonella)*; eulia (*Proeulia* spp*.)*; fruit tree weevil (*Naupactus xanthographus)*; Mediterranean fruit fly (*Ceratitis capitata)*; fruit flies (*Rhagoletis* spp., *Bactrocera* spp., *Anastrepha* spp*.)*; Chilean false red mite (*Brevipalpus chilensis)*; and *Thrips* spp.

Trials in New Zealand have shown good potential for low-temperature phosphine fumigation against horticultural pests: scale insects (*Hemiberlesia rapax* and *Aspidiotus nerii*), lightbrown apple moth (*Epiphyas postvittana*) and codling moth (*Cydia pomonella*) (Wimalaratne *et al.,* 2009). Insect resistance to phosphine is an emerging problem, particularly in developing countries. Resistance has occurred primarily because of poor sealing and non-compliance with minimum exposure times. Therefore, it is considered important to use the correct exposure and application technology to avoid development of resistance.

4.9.5.9.2. Aerosol sprays and insecticidal dips/ sprays

Aerosol sprays containing pyrethrin, permethrin and or dichlorvos are available for postharvest application. Pyrethrum aerosols are regarded as safe chemicals, have short application time, are relatively cheap, and are effective against a range of surface pests. Pyrethrum is only effective on contact with the pest and breaks down easily in sunlight.

Permigas™ (active ingredient pyrethrins, permethrin, piperonyl butoxide) is registered for used against aphids in capsicums (1.2 g/m^3 for 4-6 hours) and tropical armyworm in kumara (2 g/m^3 for 4-6 hours). Insectigas™ with 5% dichlorvos and Pestigas (active ingredient pyrethrum) are also commercially available.

Floragas™ containing pyrethrins and permethrin is registered for use against aphids and thrips on cut flowers. When protea flowers were treated in an enclosed chamber for 12 h with a combination of pyrethrin (Pestigas™) and dichlorvos (Insectigas™), both propelled by CO_2, the combination was more effective than either of the gases used alone.

Contact pesticides can be applied quickly and easily as a postharvest chemical dip or an inline, low volume spray application. Pyrethrum products are effective against a broad range of insects. They have low toxicity to other animals and a short half-life, and are regarded as an environmentally friendly alternative to many other insecticides used postharvest, such as Dimethoate. Residues need to remain below MRL limits for export markets.

There are also health and safety concerns with insecticidal dips including environmental concerns with disposal and potential costs of registration. In a situation where there is no non-chemical alternative, these chemical treatments may warrant further investigation.

4.9.5.10. Systems approach

The value of integrating pre-plant management activities and post-harvest processing when developing overall procedures to minimise the impact of insects from the field to the final packaging is well recognized (Scheider *et al,* 2003). In fact the IPPC has developed standards to this respect - ISPM 14 (2002) (see section 4.5.3. of this report).

There is a wide variety of pests of quarantine significance, varying according to origin and country of destination, that are controlled by these approved treatments. These include fruit flies, mealybug, thrip, aphids, mites and other pests. In many cases, the approved treatments apply to a particular situation, i.e. a particular commodity with particular pest(s) from a particular country or region and a particular quarantine concern of the importing country (MBTOC, 2007, 2011). Each approved treatment may be applicable to just one or several species of fruit fly, for example. However, in some cases an approved treatment covers many species, such as 'external feeders' and 'insects'.

In Chile, *Brevipalpus chilensis* is a primary pest of wine grapes and of economic importance as a quarantine pest on table grapes, kiwifruit, clementines, lemons, mandarins, custard apples, figs and persimmons. Its likely presence requires mandatory methyl bromide treatment for commodities exported to the USA and other countries (Gonzalez 2006). Stone fruit were also found to carry female *B. chilensis* hidden in the pedicel cavity at very low population densities and a few eggs were deposited down in the cavity also (less than 0.3% of fruits infested with females). The miticide dicofol was effective for controlling mites in the vineyards, and newer acaricides such as abamectin, acrinathrin, bifenthrin, propargite and spirodiclofen have also shown to be effective. With the view to reducing the use of methyl bromide treatments for table grapes exported to the USA, and documented evidence of control of this quarantine pest in the field, the Systems Approach was proposed by Chile as a condition of entry without the need for methyl bromide fumigation. Its implementation has reduced Chile's consumption of MB for QPS (Correa, pers. comm 2014).

Williams *et al.* (2000) treated oranges infested with larvae of Queensland fruit fly (*Bactrocera tryoni*) for 16-h at 20°C with an initial phosphine concentration of 0.98 gm^{-3}, which resulted in 96.4% mortality of fly larvae. Although the level of mortality was significant it was insufficient to meet the mortality requirements for interstate (99.5%) or export trade (99.9%). Exposure times, temperatures and phosphine concentrations were all increased in subsequent fumigations. In the final series of fumigations with export grade Washington Navel oranges the exposure time was 48 h at 23 or 25°C, using an initial phosphine dosage of 1.67 gm^{-3}. The concentration was topped up to about 0.7 gm^{-3} after 24 h. No adverse effects on the oranges were observed, and a mortality of 99.998% was achieved with > 48 000 larvae exposed. This would meet requirements for interstate trade in Australia and possibly also some international trade, particularly if incorporated as part of a Systems Approach.

Alternative treatments for perishable products may be carried out in the country of origin, or in-transit in some instances, or in the importing country as outlined below. However, for reasons of practicality, fumigation with methyl bromide may at present be the only available treatment in lieu of destruction or rejection of the consignment if inspection at the port of entry reveals pests of concern.

4.9.5.11. Treatments in the country of origin

Some of the approved alternative methods, notably Systems Approaches, pest free areas and pre-export inspection requirements, can only be carried out in the country of origin. For some important quarantine pest species such as fruit flies and codling moth, some importing countries require that perishable commodities undergo a mandatory treatment or procedure prior to export. Exporters sometimes prefer to carry out quarantine treatments in the country of origin for economic reasons. The cost of materials and labour for quarantine treatments can be lower in the exporting country, particularly if the destination country is a non-A5 country with higher labour costs or high charges for port demurrage.

In many cases, fixed facilities are needed for carrying out treatments e.g. heat, cold, controlled atmospheres, and it can be cheaper for the exporters to locate and operate the facilities in the country of origin than in the importing country, i.e. it is more efficient to treat all the commodity at the point of origin than to treat the commodity after it has been dispersed to several different ports. Taiwan, for example, has four vapour heat treatment facilities and pack houses which have been approved by the Australian quarantine authorities for mangoes exported to Australia, while the Philippines has five registered treatment facilities for mango (AQIS 2009). For certain treatments such as methyl bromide and heat there is a product quality penalty, however, for treating perishables before transit because the earlier treatment significantly reduces the shelf life of the treated commodity compared to treatment after transit. On the other hand, cold treatments and controlled atmospheres can improve the shelf-life and quality of perishable commodities (such as flowers and fruit) if carried out prior to export.

For perishable products, pest control based on pre-harvest practices, as part of the Systems Approach as described in ISPM No. 14, must include cultural techniques leading to pest reduction, they must have an agreement on the area of any pest-free zones, and be subject to inspection in order to receive certification. In these cases, regulatory approval depends on a number of factors including knowledge of the pest-host biology, evidence of commodity resistance to the pest, trapping and field treatment results, monitoring of pests and diseases, and careful documentation.

4.9.5.12. In-transit treatment

In some cases the approved alternative treatments (e.g. cold, controlled atmospheres) are allowed to be carried out while commodities are being transported to their destination in a truck, shipping container or ship hold that has the relevant equipment. The quarantine authorities in the USA, for example, have approved the equipment installations in a number of ships and in hundreds of shipping containers for in-transit cold treatments (CPHST 2009a, 2009b). For example, citrus shipped from Spain to the US treated by cold treatment in transit.

USDA scientists have developed a system to remotely collect, analyze and report data from long term treatments performed in transit including ships at sea. Some treatments, such as cold, can be effective alternatives to MB but require a long time to be effective but must be monitored to ensure treatment parameters are met continuously. This satellite based technology will ensure success of the treatments and prevent MB having to be used at conclusion of transit because the cold treatment went out of compliance during transit.

4.9.5.13. Treatments on arrival in the importing country

As already explained, when products arrive in an importing country and are found to need a quarantine treatment, MB tends to be the prevalent treatment in a number of countries, due to logistic issues such as a lack of rapid pest identification facilities and lack of alternative treatment facilities at ports of entry. Quarantine authorities in the USA, for example, have approved a total of about 116 quarantine treatment facilities for imported products in 28 states (primarily for methyl bromide fumigation). In many US states, only methyl bromide and phosphine facilities appear to be available at present for carrying out quarantine treatments on imported perishable products (APHIS 2008ab).

4.10. Constraints to adoption of alternatives for QPS uses

4.10.1. Economic

Methyl bromide for QPS purposes continues to be in plentiful and unrestricted supply, as expected under the exemption from phaseout under Article 2H para 6. The cost of methyl bromide gas to end users is a relatively small component of the total cost of a QPS treatment. Compliance costs associated with the handling and use of a highly toxic gas to exacting occupational, environmental and effectiveness standards, increases the overall cost of conducting QPS methyl bromide treatments. Nevertheless the methyl bromide treatment costs present a competitive barrier to the development and adoption of any new alternative processes.

Cost of methyl bromide to the end user and the fumigator, has remained relatively stable over the last 10 years, with price approximately in the range $US 4-16 per kilo in many developed and developing countries. The advantage that methyl bromide enjoys arises in part because methyl bromide based systems do not include the costs of the damage to the ozone layer and ultimately to human health. The extent of such costs is however not known. In addition, other QPS systems also have unaccounted costs to the environment and human health. Sulfuryl fluoride and heat for example, also carry environmental impacts. Again, the extent of these costs is not known.

In the absence of regulatory or economic incentives to adopt alternatives and assuming methyl bromide is in most cases the lowest cost effective system at present, an alternative would not be voluntarily adopted unless it performed as well or better at the same market cost. Technically feasible alternatives will have limited market acceptance if they are more costly – and in the world of bulk commodities, it is difficult to entice end buyers to pay a higher price for goods treated with alternatives.

If however the goal is to replace methyl bromide with alternatives while maintaining protection against high risk pests as a primary goal and market forces have not resulted complete adoption of alternatives, then alternative actions such as the following may be considered to encourage further steps.

A large number of Parties have reported no use of MB for QPS altogether as discussed previously in this Chapter. In some cases methyl bromide alternatives are in use, even though their market prices are higher. This has occurred for diverse reasons – such as health or safety concerns about methyl bromide, idiosyncratic circumstances or because the users anticipate that methyl bromide will be banned or taxed and they expect their early adoption will soon result in higher profits.

In many cases, MB is an established and traditional practice, not subjected to the rigorous and expensive efficacy testing that might be required of a new entrant in the market. It is also often the case that MB alternatives are more practical when applied at the point of origin, thus relocating the quarantine barrier offshore. More options may be available at that location including strategies to ensure product health during the production process. Factors of scale may also be relevant in this respect: large quantities of products at the point of origin may allow for more cost efficient treatment, for example by justifying installation of irradiation facilities, cold or heat treatment facilities, and others, which would not be feasible at points of entry.

However, treatment with MB often affects product quality negatively, which mainly translates into a reduced shelf life. This makes some exporters reluctant to apply treatments before export. Finally, most alternatives are more expensive than fumigation with MB at the port of entry, which further deters from their development and adoption.

4.10.2. Regulatory (including health issues)

Countries have regulations that list requirements allowing for a commodity to be imported into their boundaries, including quarantine treatment requirements. In some cases, the only treatment that is listed as acceptable is MB, indicating that there are no available data to prove the efficacy of alternatives at a level which is consistent with the country's quarantine security requirements.

Regulations prescribing MB treatment alone are a major barrier to adoption of alternatives as often there is little incentive for the regulation to be changed. Also, often the data have not been generated to prove effective control of all pests with an alternative to a standard similar to MB and Parties are unwilling to approve the alternative in the absence of this information.

Constraints to adoption of alternatives for treating soil where crops will be grown with MB are mainly regulatory – that is, alternatives not being registered at the location where treatment occurs or being restricted by regulations. Certification regulations sometimes do not recognise other treatments different to MB to achieve the high plant health status required, although developments in this respect are beginning to occur (CDFA, 2009).

The registration of a new chemical or extension of the label are often a very onerous and expensive tasks, which can take years to resolve and require considerable data on safety and efficacy. For many countries the potential volume of use is too small or cannot guarantee the intellectual property rights to justify registration.

4.10.3. Post-entry quarantine measures

Given that activity normally taken place at ports, it is frequently considered impractical to establish treatment facilities such as for irradiation or other similar measures for treating goods infested with quarantine pests due to space or environment restrictions. Further, treatments are generally performed by private contractors not government authorities, which means there has to be sufficient through-put on a continuing basis to justify the costs of facilities as well as the training and maintaining of staff to operate them. Even if treatments are available in the area, quarantine officers will often not allow the product to be moved from the port for treatment due to risks of pest dissemination. In view of this, if pests are discovered at the port of entry, it is important to have access to a wide spectrum treatment which is fast and portable, generally fumigation. Presently, four fumigants are widely available for use: methyl bromide, phosphine and, to a lesser extent, sulfuryl fluoride and HCN. For a variety of reasons including tradition, efficacy, registration, occupational health and safety issues and speed of action, methyl bromide frequently is the leading available fumigant for use at many ports at present.

Decision on the actual treatment to be applied is made by the importing country. According to the particular case, it may even be decided that no treatment is necessary.

Identification of quarantine pests, the absence of trained insect identifiers at port facilities continues to fuel the use of MB for unnecessary quarantine treatments at national Ports of Entry. Import commodities that are found to be infested with insects, mites are other quarantine organisms upon inspection at Ports of Entry are usually fumigated with MB unless the contaminating organism is identified authoritatively and confirmed to not be a pest of quarantine significance. The potential damage caused by introduced quarantine pests to the environment, agriculture, forestry and human and animal health when introduced into a country where they currently don't exist is so great that countries must provide an eradicating treatment which generally means MB. There is no doubt that unnecessary fumigations are performed because there are not resources available to the Port of Entry to make definitive identification possible.

4.11. References

Agarwal, M., Ren, Y., Newman, J., Cheng, H. 2012. Eradication of eucalyptus weevils in apples by ethyl formate. Navarro et al., 2012a, 266-271.

Anon (1993). Code of federal regulations, food and drugs. Office of the Federal Register National Archives and Records Administration, Washington DC.

APHIS (2008a) Eastern Treatment Facilities Listing by State. List of approved treatment facilities in the Eastern region, update: 10/02/08. Animal and Plant Health Inspection Service, US Department of Agriculture. http://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/Eastern_Facilities.pdf

APHIS (2008b) Western Treatment Facilities Listing by State. List of approved treatment facilities in the Western region, update: 10/02/08. Animal and Plant Health Inspection Service, US Department of Agriculture. http://www.aphis.usda.gov/import_export/plants/manuals/ports/downloads/Western_Facilities.pdf

AQIS (2009) Import Conditions database. Australian Quarantine and Inspection Service. http://www.aqis.gov.au/icon32/asp/ex_querycontent.asp

Bai J, Mielke EA, Chen PM, Spotts RA, Serdani M, Hansen JD, Neven LG (2006). Effect of high-pressure hot-water washing treatment on fruit quality, insects, and disease in apples and pears: Part I. System description and the effect on fruit quality of d'Anjou' pears. *Postharvest Biology and Technology* 40(3): 207-215.

Bell, C. H., T. J. Wontner-Smith and N. Savvidou (2003). Some properties of sulphuryl fluoride in relation to its use as a fumigant in the cereals industry. Pp 910 – 915 in: Advances in stored product protection proceedings of the 8th international working conference on stored product protection, York, UK 22-26 July 2002.

Birla S, Wang S, Tang J, Tiwari G (2008). Characterization of radio frequency heating of fresh fruits influenced by dielectric properties. *Journal of Food Engineering* 89(4): 390-398.

Cassells J., H.J. Banks and P.C. Annis (1994). Mortality of snails, *Cernuella virgata* and *Cochlicella acuta*, exposed to fumigants, controlled atmospheres or heat disinfestation. In: *Proc. 6th International Working Conference on Stored-Product Protection*, 17-23 April 1994, Canberra, Australia. pp. 50-55.

CDFA (2009). California Departent of Food and Agriculture. http://www.cdfa.ca.gov/phpps/PE/Nursery/pdfs/NIPM_7.pdf

Chervin, C., S. Kreidl, A. Hamilton and S. Whitmore (2000). "Non-chemical disinfestation: A freezing approach." *Proceedings of the XXV International Horticultural Congress*, Pt 8(518): 187-192.

Cho, J.-H, Park, C. G., Yoo, M., Kim, B.-S., Lee, B.-H. 2012. Comparative toxicity of ethyl formate for control of pests of sweet persimmons for export. Navarro et al., 2012a, 310-314.Correa, A. 2014 pers comm

CPHST (2009a) In-transit cold treatment ship database. Treatment Quality Assurance Unit, Center for Plant Health Science and Technology, Animal and Plant health Inspection Service, US department of Agriculture. https://treatments.cphst.org/vessels/printVesselDB.cfm.

CPHST (2009b) In-transit cold treatment container database. Treatment Quality Assurance Unit, Center for Plant Health Science and Technology, Animal and Plant health Inspection Service, US department of Agriculture. https://treatments.cphst.org/vessels/containerList.cfm

Cytec Industries Inc (2005). Phosphine gas products. http://www.cytec.com/business/Phonsphine/Products/PhosphineGas.shtm [accessed 1 October 2009

De Cal, A., Martínez-Terceno, A., López-Aranda, J.M. and Melgarejo P. (2004) Alternatives to methyl bromide in Spanish strawberry nurseries. Plant Disease 88(2): 210-214.

Dhouibi, M. H. 2013. Résultats des recherches menées à l'échelle nationale sur les alternatives au CH_3Br. In : Proceedings du Workshop sur les alternatives au Bromure de Méthyle pour la Desinfestation des Dattes. 15 Mai 2013 in Grand Hotel Tunis. Dowdy, A.K. (2002). Use of non-chemical methyl bromide alternatives in the USA. In: Proc. International Conference on Alternatives to Methyl Bromide. 5-8 March 2002, Sevilla. Office for Official Publications of the European Communities: Luxembourg.

Dwinell, L.D. (2001). Potential use of elevated temperature to manage pests in transported wood. Exotic Forest Pests Online Symposium, April 2001.

Emery, R.E., Chami, M., Garel, N., Kostas, E. and Hardie, D.E.(2010). The use of hand-held computers (PDAs) to audit and validate eradication of a post-border detection of Khapra Beetle, *Trogoderma granarium,* in Western Australia. Proc. 10th International Working Conference on Stored-Product Protection, Lisbon. Julius-Kühn-Archiv, 425, 1033-1039.

Faithful, I. and D. Maclaren, (2004). Branched Broomrape - Management: State prohibited weed. Department of Sustainability and Environment, State of Victoria, Australia. http://www.dse.vic.gov.au/dpi/nreninf.nsf/

Finkelman, S., Navarro, S., Navarro, H., Lendler, E. 2012. "VAPORMATETM" an alternative fumigant for QPS treatments. Navarro et al., 2012a, 247-253.

Follett, P. A. and L. G. Neven (2006). Current trends in quarantine entomology. *Annual Review of Entomology* 51: 359-385.

Furuki S. I., A. Miyanoshita and T. Imamura (2005). Toxicity of sulfuryl fluoride to the developmental stages of the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curdulionidae), at different exposure periods. *International pest control* 47(3): 133-138.

Glassey, K. (2014). Personal communication. MBTOC member, New Zealand

Gonzalez, R. H. (2006). Biology, quarantine risks and control alternatives of the grape flat mite, *Brevipalpus chilensis* Baker (Acarina: Tenuipalpidae). *Revista Fruticola* 27(3): 77-88.

Hallman, G.J. 2013. Control of stored product pests by ionising radiation. Journal of stored Products Research 52, 36-41.

Hansen JD, Heidt ML, Neven LG, Mielke EA, Bai J, Chen PM, Spotts RA (2006). Effect of high-pressure hot-water washing treatment on fruit quality, insects, and disease in apples and pears: Part III. Use of silicone-based materials and mechanical methods to eliminate surface pests. *Postharvest Biology and Technology* 40(3): 221-229.

Hara A (1997). Market quality in disinfested flowers, foliage and propagative material. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions. San Diego, California.

Hole, B.D., C.H. Bell, K.A. Mills, K.A. and G. Goodship (1976). The toxicity of phosphine to all developmental stages of thirteen species of stored product beetles. *Journal of Stored Products Research*, 12, 235-244.

Hollingsworth, R. G., Jang, E., Follett, P. 2013. Freezing as a treatment to prevent the spread of Hypaenemus jampei (Coleoptera: Curculionidae) in coffee. Journal of Economic Entomology 106, 653-660.

Hoover, K. Uzunovic, A, Gething, B. Dale, A.,Leung, K. Ostiguy, N.,and Janowiak, J., (2010) Lethal temperature for pinewood nematode, Bursaphelenchus xylophilus, in infested wood using microwave energy. In print. Presented to the Technical Panel on Phytosanitary Treatments.

Horn, P. 2012. Control of *Brevipalpus chilensis* with phosphine on fresh fruits under cold storage fumigations. Navarro et al., 2012a, 231-235.

Horn, P. 2012. Control of *Brevipalpus chilensis* with phosphine on fresh fruits under cold storage fumigations. Navarro et al., 2012a, 231-235.

Horn F, Horn P, Tumambing J, Gock D, McSwigan B (2003). Fumigation field trial tour of the Horn Diluphos System using Cytec VAPORPH3OS® on stored grain in Australia. Australian Postharvest Technical Conference. Canberra, Australia, CSIRO Stored Grain Research Laboratory. Pp. 174-182.

Horn F, Horn, P (2004). Fresh fruit fumigation with phosphine as alternative for methyl bromide. 2004 Annual Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Orlando, FL, Methyl Bromide Alternatives Outreach. Fresno, CA.

Horn FF, Horn FP, Horn PP, Horn JP, Diaz RM. (2005). Procedure of fumigation with a high concentration of pure phosphine free from ammonia at low temperature for the control of pests in fruits without damaging its quality. US patent 25265892.

Horner, I.J. (1999). Alternative soil fumigant trials in New Zealand strawberry production. In: Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, San Diego, California, USA

ICON. (2009). Timber packaging and dunnage. All countries. http://www.aqis.gov.au/icon32/asp/ex_casecontent.asp?intNodeId=8849077&intCommodityId=17670&Types=none&WhichQuery=Go+to+full+text&intSearch=1&LogSessionID=0 . Accessed 18 September 2008.

Irtwange, S (2006). Hot water treatment: a non-chemical alternative in keeping quality during postharvest handling of citrus fruits. *Agricultural Engineering International* 8: Invited Overview 5.

IMO (2008a). Recommendations on the safe use of pesticides in ships applicable to the fumigation of cargo transport units. MSC. 1/Circ. 1265. 9 June 2008. 11 pp.

IMO (2008b). Recommendations on the safe use of pesticides in ships applicable to the fumigation of cargo holds. MSC. 1/Circ. 1264. 27 May 2008. 15 pp.

IMO. (1996). Recommendations on the safe use of pesticides in ships. International Maritime Organisation, London. ISBN 92-801-1426-3.

Ingemanson, M. (1997). MIDS infrared technology – effective, benign, affordable. In: Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, November 3-5, 1997, San Diego, California.

IPPC (2006). ISPM No. 15. Guidelines for regulating wood packaging material in international trade (2002) with modifications to Annex 1 (2006). IPPC: Rome. 11 pp.

IPPC (2007) ISPM No. 28Phytosanitary treatments for regulated pests

IPPC (2008) International Standards for Phytosanitary Measures. ISPM 28: Replacement or reduction of methyl bromide as a phytosanitary measure. FAO, Roma, Italia, 9 pp.

IPPC (2009a). ISPM No. 28. Phytosanitary treatments for regulated pests. IPPC: Rome. 28 pp.

IPPC (2009b). International standards for phytosantary measures. Revision of ISPM No. 15. Regulation of wood packaging material in international trade. https://www.ippc.int/servlet/CDSServlet?status=ND0xMzM5OSY2PWVuJjMzPSomMzc9a29z

IPPC, (2011). Phytosanitary treatments for regulated pests. https://www.ippc.int/publications/phytosanitary-treatments-regulated-pests

IPPC. (2013a). ISPM 15. Regulation of wood packaging material in international trade. https://www.ippc.int/publications/regulation-wood-packaging-material-international-trade-0.

IPPC. (2013b). 2013 December ECCT meeting report. https://www.ippc.int/publications/2013-december-ecct-meeting-report

IPPC, (2014). Report of the Technical Panel of Phytosanitary Treatments, Bali, Indonesia. https://www.ippc.int/publications/2014-june-tppt-meeting-report-bali-indonesia.

Jamieson L, Dentener, PR, Krishna, H, Martin, N (2005). Effectiveness of treatments for mite eggs – a literature review. In Jamieson LE, Dentener PR, Krishna H, Martin N 2005. Effectiveness of treatment for mite eggs – a literature review, and preliminary experiments. Client Report. No. 17509.

Jeffers, L. 2014. PPQ Phytosanitary irradiation program. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 4-6 November in Orlando, FL, USA, MBAO conference, www.mbao.org, Paper 43.

Jeffers, L., Thoms E. M., Morgan, M. 2012. ProFume® gas fumigant: A Methyl Bromide alternative for US log exports to China. In: Obenauf, G. L. (ed.), Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 6-8 November in Orlando, FL, USA, MBAO conference, www.mbao.org, MBAO, 33-1.

Jiao, S., Johnson, J. A., Tang, J., Wang, S. 2012. Industrial scale radio frequency treatments for insect control in lentils. Journal of stored Products Research 48, 143-148.

Kim J, Yousef A, Dave S (1999). Application of ozone for enhancing the microbiological saftey and quality of foods: a review. *Journal of Food Protection* 62(9): 1071-1087.

Kostyukovsky, M., U. Ravid and E. Shaaya (2002). The potential use of plant volatiles for the control of stored product insects and quarantine pests in cut flowers. *Acta Horticulturae* 576: 347-358.

Lacey, L. A., D. R. Horton, D. C. Jones, H. L. Headrick and L. G. Neven (2009). Efficacy of the biofumigant fungus *Muscodor albus* (Ascomycota: Xylariales) for control of codling moth (Lepidoptera: Tortricidae) in simulated storage conditions. *Journal of Economic Entomology* 102(1): 43-49.

Lagunas-Solar M, Essert T, Pina U, Zeng N, Truong T (2006). Metabolic stress disinfection and disinfestation (MSDD): a new, non-thermal, residue-free process for fresh agricultural products. *Journal of the Science of Food and Agriculture* 86(12): 1814-1825.

Lagunas-Solar M, Pan Z, Zeng N, Truong T, Khir R, Amaratunga K (2007). Application of radiofrequency power for non-chemical disinfestation of rough rice with full retention of quality attributes. *Applied Engineering in Agriculture* 23(5): 647-654.

Lee, B.-H., Kang, M.-K., Park, M.-G., Sung, B.-K., Kim, T.-J. 2009. Commercial application of Vapormate™ as quarantine fumigant in imported fruits. In: Proceedings of the regular meeting of the pesticide science society of Korea, 57

Linde 2013 http://cropscience.linde-gas.com/en/products_services/vapormate.html

Liu, Y.-B. 2011. Potential of oxygenated phosphine fumigation for postharvest pest control. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 31 October – 2 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 53-1 – 53-4.

Liu, Y.-B. 2012. Oxygenated phosphine fumigation for control of *Nasonovia ribisnigri* (Homoptera: Aphidae) on harvested lettuce. Journal of Economic Entomology 105, 810-816.

Lopez-Aranda, J 2012. Methyl Bromide Alternatives (Chemical and Nonchemical) for Strawberry Cultivation in Conventional Areas of Production. Proceedings of the VII International Strawberry Symposium 2012, Beijing, China. *ActaHorticulturae*

MAFF (Ministry of Agriculture, Forestry, and Fisheries) (1971). Quarantine prospectus for import grains. Director's notice Nosei, No.2628, 6 February 1971 (in Japanese)

Manickavasagan, A., Alahakoon, P. M. K., Al-Busaidi, T. K., Al-Adawi, S., Al-Wahaibi, A. K., Al-Raeesi, A. A., Al-Yahyai, R., Jayas, D. S. 2013. Disinfestation of stored dates using microwave energy. Journal of stored Products Research 55, 1-5.

Strike out, in QPS: Mayfield III, A. E., Fraedrich, S. W., Taylor, A., Merten, P., Myers, S. W. 2014. Efficacy of heat treatment for the thousands cankers disease vector and pathogen in small black walnut logs. Journal of Economic Entomology 107, 174-184.

Mann, R.C., Mattner, S.W., Gounder, R.K., Brett R.K. and Porter I.J. (2005). Evaluating novel soil fumigants for Australian horticulture. Pp 34-1 – 34-4 In: Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, Oct 31 - Nov. 3 2005, San Diego, California, USA.

Margosan S, Smilanick J (2002). Mortality of *Botrytis cinerea*, *Monilinia fructicola*, *Penicillium digitatum*, and *Rhizopus stolonifer* spores after exposure to ozone gas. http://postharvest.ucdavis.edu/Ipm/objectives_2000.shtml#margosan2 [accessed 1 October2009

Mattner, S. Porter, I.J., Gounder, R.K., Guijarro, B. Williams, E.N. (2010). Maintaining biosecurity and market access in the Australian strawberry industry following methyl bromide phase out. *Acta Horticulturae* 883 99-106.

MBTOC (1995). 1994 Assessment Report of the Methyl Bromide Technical Options Committee. UNEP, Nairobi.

MBTOC (1998). 1998 Assessment Report of the Methyl Bromide Technical Options Committee. UNEP, Nairobi.

MBTOC (2002). 2002 Assessment Report of the Methyl Bromide Technical Options Committee. UNEP Nairobi.

MBTOC (2007). 2006 Assessment Report of the Methyl Bromide Technical Options Committee. UNEP, Nairobi, Kenya, 485 pp.

MBTOC (2011). 2010 Assessment Report of the Methyl Bromide Technical Options Committee. UNEP, Nairobi Kenya, 400 pp.

Misumi, T., M. Aoki and H.Kitamura 2011. Synergistic and suffocative effects of fumigation with a lower-concentration phosphine and sulfuryl fluoride gas mixture on mortality of Sitophilus species (Coleoptera: Dryophthoridae), a stored-product pest. part 2: Susceptibility test on *Sitophilus zeamais* for fumigation with a gas mixture, and verification test of a sequential fumigation with two fumigants. Res. Bull. Pl. Prot. Japan 47 (In press).

Misumi T., Ogawa, N., Yamada, K., Shukuya, T. 2013a. Susceptibilities of five species of scales (Diaspididae and Coccidae) and mealybugs (Pseudococcidae) to fumigation with a gas mixture of ethyl formate and carbon dioxide under normal atmospheric pressure or vacuum. Res. Bull. Pl. Prot. Japan 49, 1-9.

Misumi T., Yamada, K., Naito, H., Ogawa, N., Shukuya T. 2013b. Influence of gas mixture fumigation of ethyl formate and carbon dioxide on several characteristics of fresh fruits and vegetables (bananas, pineapples, strawberries, grapefruits, Satsuma mandarins, squashes and other vegetables). Res. Bull. Pl. Prot. Japan 49, 19 - 27.

Mitcham, E., Pupin, F., Bikoba, V., Basi, B. 2011. Control of bean thrips and light brown apple moth with Vapormate[TM]. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 31 October – 2 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 51-1 - 51-2.

Mori, T. and N. Kawamoto (1966). Studies on the properties and effect of fumigant aluminum phosphide. *Research Bulletin of Plant Protection Japan* 3:24–35 (in Japanese).

Morrell, J.J (1995). Importation of unprocessed logs into North America: A review of pest mitigation procedures and their efficacy. *Forestry Products Journal* 45(9):41-50.

Navarro, S., E. Donahaye, G. C. Sabio, M. Rindner, R. Dias and A. Azrieli (1999). Reducing MB dosage or exposure time using CO_2 with methyl bromide or CO_2 with heat. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, California, USA.

Navarro, S. 2006. Postharvest treatment of dates. Stewart Postharvest Review 2, 1-9.

Neven, LG and L. Rehfield-Ray (2006). Combined heat and controlled atmosphere quarantine treatments for control of western cherry fruit fly in sweet cherries. *Journal of Economic Entomology* 99(3): 658-663.

Neven, LG and L. Rehfield-Ray (2006b). Confirmation and efficacy tests against codling moth and oriental fruit moth in apples using combination heat and controlled atmosphere treatments. Journal of Economic Entomology 99(5): 1620-1627.

Nevin L, Drake S 2000. Comparison of alternative postharvest quarantine treatments for sweet cherries. Postharvest Biology and Technology 20: 107-114.

Obra, G. B., Resilva, S. S., Follett, P. A., Lorenzana, L. R. J. 2014. Large-scale confirmatory tests of a phytosanitary irradiation treatment against *Sternochetus frigidus* (Coleoptera: Curculionidae) in Philippine mango. Journal of Economic Entomology 107, 161-165.

Papadimitriou V. C., R.W. Portmann, D.W. Fahey, J. Mühle, R.F. Weiss and J.B. Burkholder (2009). Experimental and theoretical study of the atmospheric chemistry and Global Warming Potential of SO2F2. *Journal of Physical Chemistry* A, 2008, 112 (49): 12657-12666.

Potter, MA, Carpenter, A, Stocker, A and Wright, S (1994). Controlled atmospheres for the postharvest disinfestation of *Thrips obscuratus* (Thysanoptera:Tripidae). *Journal of Economic Entomology* 87(5): 1251-1255

PPS (Plant Protection Statistics) (2007) Report of imported plants for categories in 2007 (in Japanese).

Pupin, F., Bikoba, V., Biasi, W. B., Pedroso, G. M., Ouyang, Y., Grafton-Cardwell, E., Mitcham, E. J. 2013. Postharvest control of western flower thrips (Thysanoptera: Thripidae) and California red scale (Homoptera: Diaspididae) with ethyl fromate and its impact on citrus fruit quality. Journal of Economic Entomology 106, 2341-2348.

Purohit, P., Jayas, D.S., Yadav, B.K., Chelladurai, V., Fields, P.G., White, N.D.G. 2013. Microwaves to control *Callosobruchus maculatus* in stored mung bean (*Vigna radiata*). Journal of stored Products Research 53, 19-22.

Reichmuth, C.H. (2002). Alternatives to methyl bromide for the treatment of wood, timber and artefacts in the European community. In: International Conference on Alternatives to Methyl Bromide, March 2002, Seville, Spain.

Ren, Y. L., Lee, B.-H., Padovan, B. 2011. Penetration of methyl bromide, sulfuryl fluoride, ethanedinitrile and phosphine into timber blocks and the sorption rate of the fumigants. Journal of stored Products Research 47, 63-68.

Rhatigan, R.G., Morrell, J.J. and Filip, G.M. 1998. Toxicity of methyl bromide to four pathogenic fungi in larch heartwood. Forest Products Journal 48: 63-67.

Rodas, R. (2013). Uso de Bromuro de Metilo en cuarentena y pre-embarque en Centroamérica. En: Taller sobre Alternativas al Bromuro de Metilo, Managua, Nicaragua Diciembre 12 y 13 de 2013 (UNEP/ MARENA)

Rodríguez, J.C., J.F. Rodríguez and J. García 2010. Tolerancia de estados inmaduros de *Anastrepha fraterculus* (Diptera: Tephritidae) al fosfuro de magnesio. Resúmenes Sociedad Colombiana de Entomología (Socolen) XXXVII Congreso, Bogotá, Colombia, Junio 30- Julio 2, 2010.

Schaub, J. MBTOC member. pers. comm. 2010

Scheffrahn, R.H. and E.M. Thomas (1993). Penetration of sulfuryl fluoride and methyl bromide through selected substrates during fumigation. *Down to Earth* 48 (1).

Schneider, S.M., E.N. Rosskopf, J.G. Leesch, D.O. Chellemi, C.T. Bull & M. Mazzola. 2003. USDA-ARS Research on alternatives to methyl bromide: Pre-plant and post-harvest. Special issue: Pest management research in the USDA Agricultural Research Service. *Pest Management Science* 59(6/7): 814-826.

Scott Boothey (2010) Personal communication.

Semple, R. L. and K.I. Kirenga. (1997). Facilitating regional trade of agricultural commodities in Eastern, Central and Southern Africa. Phytosanitary standards to restrict the further rapid spread of the larger grain borer (LGB) in the region. Dar es Salaam, Tanzania. Dar Es Salaam University Press.

Shellie K, Mangan R (1995). Heating rate and tolerance of naturally degreened 'Dancy' tangerine to high temperature forced air for fruit fly disinfestation. *Hort Technology* 5(1): 40-43.

Spotts RA, Serdani M, Mielke EA, Bai J, Chen PM, Hansen JD, Neven LG, Sanderson PG (2006). Effect of high-pressure hot water washing treatment on fruit quality, insects, and disease in apples and pears: Part II. Effect on postharvest decay of d'Anjou pear fruit. *Postharvest Biology and Technology* 40(3): 216-220.

Stejskal, V., O. Douda, M. Zouhar, M. Manasova, M. Dlouhy, J. Simbera and R. Aulicky (2014) Wood penetration ability of hydrogen cyanide and its efficacy for fumigation of *Anoplophora glabripennis*, *Hylotrupes bajulus* (Coleoptera), and *Bursaphelenchus xylophilus* (Nematoda), International Biodeterioration & Biodegradation 86: 189 -195.

Tateya, A. (2010). MBTOC member pers. comm.

TEAP. (1999). Report of the Technology and Economic Assessment Panel April 1999, Volume 2: Essential Use Exemptions, QPS Applications for Methyl Bromide, Progress and Control of Substances and other Reporting Issues. UNEP:Nairobi: 227pp.

TEAP (2002) . Report of the Technology and Economic Assessment Panel May 2002. UNEp Nairobi, 110 pp,

TEAP (2009a). Report of the Technical and Economic Assessment Panel. May, 2009. Ozone Secretariat, UNEP, Nairobi

TEAP (2009b). Report of the Technology and Economic Assessment Panel. QPSTF Report. UNEP, Nairobi

TEAP. (2006). Report of the Technology and Economic Assessment Panel. Progress Report. May, 2006. Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations Environment Programme, Nairobi

TEAP (2007). Report of the Technology and Economic Assessment Panel. Progress Report. May, 2007.

TEAP (2003). Report of the Technology and Economic Assessment Panel. Progress Report. May, 2003.

TEAP (2010). Report of the Technology and Economic Assessment Panel. Progress Report. May, 2010.

TEAP (2012). Report of the Technology and Ecoonomic Assessment Panel Progress Report, May 2012.

Thalavaisundraram, S., Roynon, J. 2012. Penetration capacity of VAPORMATE™ TM into commercially plastic wrapped cardboard boxes filled with sultanas for controlling stored product pests. In: Navarro et al., 2012a, 384-388.

Tiwari G, Wang, S, Birla, SL, Tang, J (2008). Effect of water-assisted radio frequency heat treatment on the quality of 'Fuyu' persimmons. *Biosystems Engineering* 100(2): 227-234.

Tumambing, 2013. ECO2FUME phosphine fumigant as a prinary alternative to methyl bromide for QPS application in Indonesia. MBAO 4-6 November 2013, San Diego, California, USA

UNEP/ IPPC, (2008). Methyl Bromide: Quarantine and Preshipment uses. United Nations EnvironmentProgramme, Nairobi, Kenya, 16 pp.

UNEP/ ROAP (2008). Report to UNEP CAP ROAP Programme Bangkok. Quarantine and preshipment used for methyl bromide in ROAP and potential for their replacement. Prepared by Jonathan Banks, 45 pp

USDA (1992): Pest risk assessment of the importation of *Pinus radiata* and Douglas fir logs from New Zealand. USDA, Forest Service. Miscellaneous Publication No. 1508

USDA. (1994). Importation of logs, lumber, and other unmanufactured wood articles: environmental impact statement.

USDA. (1996). Importation of logs, lumber, and other unmanufactured wood articles. 7CFR319.40 USDA Animal and Plant Health Inspection Service. Washington, DC.USDA 1996

USDA. (2009). PPQ Treatment Manual. http://www.aphis.usda.gov/import_export/plants/manuals/ports/treatment.shtml. Accessed Accessed 20 September 2009.

USDA (2001). United States Department of Agriculture AQIS Treatment manual

USEPA (1996). Heat treatment to control pests on imported timber. Methyl bromide case study, 10 case studies, Volume 2. U.S. Environmental Protection Agency. http://mbao.org/heatlog2.html [accessed 1 October 2009

Valerio, A. 2014. Pers comm. Alejandro Valeiro, MBTOC member

Waddell B, Cruickshank, VM, Dentener, PR (1988). Postharvest Disinfestation of *Nysius huttoni* on 'Granny Smith' apples using controlled atmosphere coolstorage DSIR.

Waddell B, Edwards G, Jamieson L, Laidlaw W (2004). Streamlining development of postharvest heat treatments for disinfesting fruit. *International Congress of Entomology*. Brisbane.

Wang, D., Tang, J., Johnson, J. A., Cavalieri, R. P. 2013. Heating uniformity and differential heating of insects in almonds associated with radio frequency. Journal of stored Products Research 55, 15-20

Watson, C.R., Pruthi, N., Bureau, D., Macdonald, C. and J. Roca. (1999). In transit disinfestation of bulk and bagged commodities: a new approach to safety and efficiency. In: Proc. *7th International Working Conference on Stored-product Protection*, Beijing, 1998, pp. 462-471.

Whiting D, Jamieson, LE, Spooner, KJ, Lay-Yee, M (1999). Combination high-temperature controlled atmosphere and cold storage as a quarantine treatment against *Ctenopseustis obliquana* and *Epiphyas postvittana* on 'Royal Gala' apples. Postharvest Biology and Technology 16(2): 119–126.

Whiting D, Jamieson, LE, Connolly, PG (2000). Mortality responses of the brownheaded and black-lyre leafrollers to controlled atmosphere and air cold storage treatments for kiwifruit. *New Zealand Plant Protection* 53: 365-370.

Whiting D (2003). Potential of controlled atmosphere and air cold storage for postharvest disinfestation of New Zealand kiwifruit. 8th International CA Conference, *Acta Horticulturae* ISHS. Pp. 143-147.

Williams P, Hepworth, G, Goubran, F, Muhunthan, M, Dunn, K (2000). Phosphine as a replacement for methyl bromide for postharvest disinfestation of citrus. *Postharvest Biology and Technology* 19(2): 193-199.

Williamson M and Williamson J (2003). Heat-based quarantine technologies (post harvest disinfestation): current status and future opportunities in the Pacific region. Australian Postharvest Horticulture Conference. Brisbane, Australia. Pp. 106-108.

Wimalaratne SK, van Epenhuijsen CW, Brash DW, Page BBC, Somerfield KG, Bycroft BL, G MAR, Klementz D 2009. Control of codling moth larvae and eggs using phosphine at coolstore temperatures. Plant & Food Research Confidential Report. No. 2406.

Yamada, K., Shukuya, T., Ogawa, N., Misumi, T. 2012. Mortality test of ethyl formate fumigation for leaf miner (*Liriomyza sativae*, *Liriomyza trifolii*) and Spider Mite (*Tetranychus cinnabarinus*, *Tetranychus kanzawai*). Res. Bull. Pl. Prot. Japan 48, 13□17 .

Yu K.Y., Y.W. Chung, M.H. Lee and J.W. Jae. (1984). Study on shipboard fumigation of the imported logs. *Korea Journal of Plant Protection* 23: 37-41.

Zasada, I.. Walters A.T.W., and Hanson B.D.,. (2010). Challenges in Producing Nematode- and Pathogen-free Fruit and Nut Nursery Crops in the United States. Outlooks on Pest Management 21:246-250.

Zhang, F., Y. Wang, B. Liu, L. Ren, S. Gong and L. Tao. (2015). Low temperature phosphine fumigation for postharvest control of western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae) on oriental lily. Postharvest Biology and Technology 100: 136-141.

5

Chapter 5. Chemical and non-chemical alternatives to Methyl Bromide for pre-plant soil uses

5.1 Introduction

Since the 2010 Assessment Report, widespread adoption of alternatives to methyl bromide (MB) for pre-plant soil fumigation has occurred in many A5 and non-A5 countries previously using MB for preplant soil fumigation, whether as controlled uses (A5 Parties) or as critical uses (non-A5 Parties) with MB. MBTOC has identified feasible alternatives for virtually all soil uses of MB; however, regulatory barriers and cost may restrict their full adoption across all sectors worldwide.

This chapter focuses on economically and technically feasible alternatives for pre-plant soil fumigation, both chemical and non-chemical. Over the years, MBTOC has identified various key chemical alternatives that perform consistently across most regions and sectors for example, 1,3-D/Pic, Pic alone, a 3-way treatment involving 1,3-D, Pic and metham sodium, DMDS, and many non-chemical alternatives. The latter include for example resistant cultivars, grafting, substrates, steam, solarisation, biofumigation, organic amendments, anaerobic soil disinfestations (ASD) and biological control. There are now numerous examples of key productive sectors around the world (A5 and non-A5) previously using MB, which have successfully adopted these alternatives in a wide range of cropping systems. A combined IPM approach has most often yielded the best results.

The 2014 MBTOC Assessment Report focuses primarily on those alternatives that have been adopted by a significant number of users. However, effective soil treatments thatmay be limited to specific areas due to, for example the availability of active ingredients, climatic factors, cultural practices, regulatory constraints and economic issues are also addressed. A large number of research and review articles have been published on alternatives to MB and at least two thorough meta-analyses considering hundreds of international studies (Porter *et al.,* 2006, Belova *et al*., 2013) now provide the Parties with information on the relative effectiveness of alternatives in many sectors.

In 2014, the total amount of MB nominated for soil critical uses was 917.191 t. This amount represents 4 % of the amount nominated in 2005 (18,704.241 t) (TEAP, 2014a). In 2005, MB for critical uses was requested by 10 non-A5 countries in addition to the European Union. In 2014, 3 non-A5 countries submitted nominations for critical uses of MB (for use in 2016) and for the first time, by 3 A5 countries (for 2015). This is in clear contrast with over 100 CUNs submitted in 2003 for 2005, when the critical use process began for non-A5 Parties.

5.2. Chemical alternatives

Soil-borne pathogens(fungi, bacteria, viruses and nematodes), weeds and some insect pests can cause serious losses in various crops, especially in intensive cultivation cropping systems, and this is often a reason why growers resort to fumigating the soil.

Since the 2010 MBTOC Assessment Report, important changes in the registration and commercial adoption of chemical alternatives to MB have taken place. In all EU member states for example, fumigants once regarded as MB alternatives (chloropicrin, 1,3-D, MITC generators) are now subject to increasingly stringent regulations restricting or even preventing their use (e.g. European Directives 91/414/EEC, 2009/128/EC, Colla *et al.,* 2014). Since 2008 efforts to register two new fumigants- iodomethane (methyl iodide, MI) and dimethyl disulfide - were conducted in several countries, however MI registration has subsequently been withdrawn by the manufacturer almost worldwide. Further, some initially promising chemicals included in the previous MBTOC reports have seen little further development, for example propargyl bromide, sodium azide, propylene oxide, formaldehyde, carbonyl sulphide and cyanogen. Alternative fumigants that are currently available and widely used are described in more detail in the following sections.

5.2.1 Single chemical alternatives

5.2.1.1 Chloropicrin

Chloropicrin (trichloronitromethane) (Pic) is effective for controlling soilborne fungi and some insects but has limited activity against weeds (Ajwa *et al.,*2003). Pic has provided satisfactory and consistent control of various soil borne fungal diseases in many crops including vegetables, ornamentals and ginger (Gullino *et al.,* 2002;Chow 2009;Li *et al.,* 2014a).

Pic applied in conjunction with virtually or totally impermeable films (VIF, TIF) has been shown to be an effective strategy to reduce application rates whilst keeping satisfactory efficacy (Chow, 2009).However, the increase in Pic use in the strawberry sector following MB phaseout has been reported to lead to a higher incidence of *Macrophomina phaseolina* in many countries such as Israel (Zveibil and Freemen, 2005, 2009), USA (Daugovish, 2011ab; Koike, 2008, Koike *et al* 2009), Australia (Fang *et al.,* 2011ab) and Spain (Avilés *et al.,* 2008, 2009).In addition, regulatory constraints continue to limit Pic use in some countries.

Pic at 40 g/m^2 provided control of diseases of ginger at levels similar to those achieved with MB. This treatment yielded excellent long-term control of all target pathogens.Pic injection covered with VIF, is considered an effective alternative for control of the major soilborne pathogens of ginger in Shandong (Li *et al.,* 2014a).

5.2.1.2. 1,3-Dichloropropene (1,3-D)

1,3-D is an effective nematicide, which also control of insects, some weeds and pathogenic fungi (Ajwa *et al.,*2003; Qiao *et al.*, 2010, 2011, 2012abc .) This fumigant can achieve similar efficacy to MB when combined with high barrier films (VIF, TIF) at reduced dosages (Chow, 2009).

In California, USA, agricultural fumigant use regulations restrict complete transition from MB to alternative fumigants. 1,3-D and Pic are being used on approximately half of California strawberry production fields, but geographic use limits and buffer zones set by the California Department of Pesticide Regulation for 1,3-D/Pic restrict a more complete replacement of MB with this option (Jayesh *et al.,* 2011.)

Xiaoxue *et al.,* (2013) reported that Telone C-35, a commercial formulation of 1,3-D/Pic, significantly reduced the germination of many weed seeds such as *Digitaria chinensis*, *Eleusina indica*, *Portulaca oleracea* and *Stellaria media,* while maintaining high marketable tomato yields, with no significant differences withMB/Pic.

A gelatin capsule formulation of 1,3-D/Pic developed in China produces less environmental emissions and potential human hazards than 1,3-D/Pic used as a fumigant. The gel capsule formulation was reported to reduce soil populations of *Fusarium* spp., *Phytophthora* spp., *Pythium* spp. and *Meloidogyne* spp. at a dosage 30 or 50g/m^2, whilst producing marketable yields equal to those obtained with either MB or1,3-D/CP liquid injection treatments (Wang *et al*., 2013)

5.2.1.3. Methyl isothiocyanate (MITC)

Methyl isothiocyanate (MITC) fumigants such as dazomet, metham sodium, metham ammoniun and metham potassium, are highly effective for controlling a wide range of arthropods, soilborne fungi, nematodes and weeds, but less effective against bacteria and root-knot nematodes. In California, US, early season severe stunting from sting nematode was observed within the untreated controls and all metham sodium and metham potassium treatments (Noling and Cody, 2013). MITC fumigants prove more effective when combined with Pic and/or 1,3-D. This is the basis for the very effective 3-way system developed in the South East USA, which is widely used at present (Culpepper, 2008).

5.2.1.4. Dimethyl disulfide (DMDS),

DMDS is now registered in many A5 and non-A5 countries. It has been recently registered in the US, but not yet in California, so cannot presently be considered as an alternative for the Californian strawberry fruit sector (Belova *et al.,* 2013; Devkota *et al.,* 2013). DMDS has proven highly efficient for the control of various soil-borne nematodes of many crops including tobacco (Zannon *et al.,* 2014), carrot (Curto *et al.,* 2014) and other vegetables in different countries (Abuzeid 2014; Heller *et al* 2009,2010; Sasanelli *et al.,* 2014: Westerdhal and Beem, 2013; Leocata *et al.,* 2014; Fritch *et al.,* 2014). This fumigant can also control yellow nutsedge (*Cyperus* spp) (McAvoy and Freeman, 2013) and its efficacy can be enhanced when applied with VIF or TIF films (Fouillet, *et al.,*2014).

5.2.1.5. Allyl isothiocyanate (AITC)

Allyl isothiocyanate (AITC or mustard oil) is a naturally occurring pungent compound that is widely used as a culinary herb and in traditional medicine (Alpizar *et al*., 2014). Isothiocyanates (ITCs) are sulfur-containing compounds produced by many members of *Brassicaceae* plant family (Avato et al., 2013). AITC compounds have shown insecticidal and herbicidal activity and research has demonstrated that they can have practical application for weed control in polyethylene-mulched fields (Bangarwa *et al.,* 2012; Devkota *et al.,* 2013). Based on toxicity data, AITC has been found to have potential as a fumigant for controlling some insects (Paes *et al*., 2012; Saglam and Ozder, 2013; Yilmaz and Tunaz, 2013) and can also be used as a pre-plant soil fumigant alternative for broad-spectrum control of weed seeds, nematodes and diseases (Allan and Leon, 2013; Wu *et al*., 2011). AITC was registered in the USA in September 2013 (but not in California) for eggplant, pepper, tomato, carrot, onion, potato, strawberry, asparagus, broccoli, cauliflower, cucumber, squash, melons and turf. Its small buffer zone requirement gives it an advantage over other fumigants.

AITC is expected to be registered in the near future in other countries including Mexico, Canada, Italy, Spain, Turkey, Morocco, Japan and Israel (Allan and Leon,2013).

5.2.1.6 Sulfuryl fluoride

Sulfuryl fluoride (SF) is an insecticide fumigant gas, widely used for insect and rodent control in post-harvest commodities. It is also used to treat structures, vehicles and wood products for controlling drywood termites, wood-infesting beetles and other insect pests. In China, SF is registered as a nematicide fumigant for cucumber since 2014, at a rate of 50-70g/m^2 (Cao *et al.,* 2014). SF has a shorter plant-back time than other fumigants including MB and can be applied when soil temperatures are low , due to its low boiling point.These features give this fumigant a significant advantage over other soil fumigants.

5.2.1.7 Abamectin

Abamectin is formulated as a mixture of 80% avermectin B_{1a} and 20% avermectin $B_{1b,}$both being fermentation products of *Streptomyces avermitilis*, a naturally occurring soil actinomycete. Trials and commercial use in China have shown good efficacy of this product for the control of nematodes (Qiao *et al.,* 2012). Abamectin is registered in China and is considered a key alternative to MB for the control of nematodes in cucumber, tomato, watermelon, pepper and tobacco crops.

5.2.1.8 Fluensulfone

Fluensulfone (Nimitz, MCW-2) is a new nematicide, showing good efficacy for nematode control in carrot, cucumber and cantaloupe at rates of 2-8 kg/Ha. Results were found to not differ significantly from1,3-D at 84l/ha (Westerdahl and Chiller ., 2014).

5.2.1.9 Fungicides

Phytophthora capsici crown and root rot of squash is difficult to manage because all commercial cultivars are highly susceptible to this soil borne pathogen.Vegetable growers have traditionally relied on foliar fungicide applications to control this pathogen, despite their limited and inconsistent efficacy. Foliar, drip chemigation and soil drenches with fungicides have recently gained interest as a mean to improve control of *P. capsici* (Meyer and Hausbeck, 2013) as in general they are more effective than foliar applications. Drenches of fluopicolide, mandipropamid, or dimethomorph also reduce plant death and prevent yield loss associated with root and crown rot, an effect generally not achieved with foliar applications of these same compounds (Meyer and Hausbeck, 2013).

5.2.2 Combinations of chemical alternatives

Combined fumigant treatments can expand the pest control spectrum and lead to performance levels that match and even surpass those of MB. A well-known commercial product is the mixture of 1,3-D and Pic, which is sold under brand names such as Telopic™, Telodrip™, Inline™ and others and is widely used to control soil borne nematodes and fungi (Ajwa *et al.,*2003;Gamliel *et al.,* 2005;Minuto *et al.,*2006.) Combined treatments can help decrease the likelihood of some fumigants quickly degrading in soils. Accelerated degradation and loss of activity of metham sodium which reportedly occurs in some soil types can be reduced when using a formalin-metham sodium mixture, that effectively controls *Verticillium* wilt and other diseases (Triky-Dotan *et al.,*2009). Fumigant mixtures can however lead to negative interactions and may thus present challenges, such as needing to apply the products sequentially to avoid problems. Further research is needed to explore additional effective fumigant combinations.

Fumigant mixtures or sequential applications integrating non-chemical control practices (an IPM approach) have been shown to provide pest control and yield increases equivalent to those achieved with MB. Two statistical analyses on strawberry fruit and tomato crops have shown that across a wide variety of locations, climates, soil conditions and pest pressures, a number of chemical combinations have consistently shown equivalent effectiveness to MB (Porter *et al.,*2006; Belova *et al.,* 2013).

5.2.2.1. 1,3-D/ Pic

As mentioned earlier, 1,3-D and Pic are widely used in co-formulations for pre-plant control of nematodes, weeds and fungi. Recently, more stringent regulations to control soil-air emissions of these fumigants have encouraged research to reduce their emission potential. Information has become available, which can be used to refine buffer zone estimates for chloropicrin where it is applied at lower rates (Ashworth *et al.,* 2013).

1,3-D/Pic is a key alternative to MB,which is widely accepted commercially for controlling soil nematodes and fungi and has consistently shown to be as effective as MB (Ajwa *et al.,*2003, 2004; Minuto *et al.,*2006; Porter *et al.,*2006; Ji *et al.*, 2013). Application costs are similar or lower than those of MB. Various formulations of 1,3-D/Pic are currently registered in many countries, with TC-35 being the main one replacing MB.In the EU however, decisions related to 1,3-D and soon expected for Pic may significantly change the availability of these chemicals (e.g. European Directives 91/414/EEC, 2009/128/EC) (Colla *et al.,* 2014), with serious impact for example in Spain, where the majority of productive sectors previously using MB had switched to 1,3-D/Pic by 2006 (Porter *et al.,*2006).In the US, present regulations on 1,3-D relating to regional quotas (e.g. township caps), buffer zones, karst topography and mandatory personal protective equipment are regularly under review this has somewhat restricted its uptake as an alternative toMB in California and Florida. Further, application of 1,3-D/Pic in heavy, cold soils (<10°C) can result in phytotoxicity issues for example in strawberry runner crops (Mattner *et al.,* 2014) and in vegetables (Desager and Csinos, 2005).

A gelatin capsule formulation of 1,3-D/Pic developed in China has been previously described.

5.2.2 2. 1,3-D and MITC

Combinations of 1,3-D and MITC fumigants have been used in Europe, as well as in Canada and other countries, (although their future availability in EU countries is uncertain Colla *et al.,* 2014). 1,3-D combined with metham sodium increases control of weeds and soilborne pathogens (Ajwa *et al.,* 2003). In particular, sequential application of metham sodium following reduced rates of 1,3-D/Pic EC or Pic alone controls soilborne pests in strawberries and produces yields equivalent to standard MB/Pic fumigation, without any negative effects (Ajwa and Trout .,2004). This combined treatment may however be limited by longer plant-back periods, degradation in sandy soils and some compatibility issues with otherfumigants (Ajwa *et al.,* 2003). A combined treatment of 1,3-D and dazomet was found to be more effective than either1,3-D or dazomet alone and provided results similar to methyl bromide with respect to pest control, plant mortality and plant yield (Mao *et al,*. 2012).

5.2.2.3. MITC, 1,3-D/Pic

The combination of these three fumigants has gained interest in the last ten years as a highly effective option to control nematodes, fungi, weeds and soil insects However it can be phytotoxic and may require long plantback periods (Porter *et al.,* 2006, 2007). The product was withdrawn from registration in the USA in 1992, but is still registered in Canada, Mexico and other countries, and has outperformed MB for control of pathogens in trials on strawberries in Australia (Porter *et al.,* 2006). It was found to provide better fungal, nematode and weed control than 1,3-D/Pic alone (Ajwa *et al.,*2002; Porter *et al.,*2006: Candole *et al.,*2007).

5.2.2 4. Formalin and metham sodium

A mixture of formalin and metham sodium (MS) can broaden the pathogen control spectrum and result in a synergistic effect particularly with respect to fungal pathogens; it can also be used in soils prone to accelerated degradation of MS (Di-Primo *et al.,* 2003; Gamliel *et al.,*2005; Tricky-Dotan *et al.,*2009). It is reported to control *Fusarium oxysporum* f.sp. *radicis-lycopersici, Monosporoascus cannonballus*, and *Rhizoctonia solani*, which are often difficult to control with other chemicals. The synergistic effect was also evident at reduced dosages (Di-Primo *et al.,*2003; Gamliel *et al.,* 2005). Formalin and MS react strongly when mixed together, so should be applied from separate containers (Gamliel*et al.,*2005).

5.2.2.5. Dazomet/1,3-D and dazomet/DMDS

Combinations of 1,3-D and dazomet displayed positive synergistic activity on nematodes, soil-borne fungi and weeds in laboratory trials (Van Wambeke 2007; Van Wambeke *et al.,*2009; Mao *et al.,* 2012). Field trials also showed good control of soilborne disease at levels equivalent to MB with respect to plant mortality, plant height, and yield in greenhouse cucumber (Mao *et al.,* 2012). A combination of DMDS and dazomet at half dose rate revealed positive synergistic effects on nematodes, soilborne fungi and weeds (Van Wambeke *et al.,* 2009; Mao *et al.,* 2014a). Greenhouse trials on cucumbers also yielded good results (Mao *et al.,*2014b).

5.2.2.6. Chloropicrin/DMDS

In fresh market tomato, DMDS/Pic offers an effective alternative to MB for managingyellow nutsedge and other soil-borne pests in tomato (McAvoy and Freeman , 2013).

Pic was first used on strawberry crops in California, USA , to control Verticillium wilt and other soil-borne fungi. DMDS has shown good control of several soilborne fungi and nematodes in trials conducted in France, Italy, and California (García-Méndez *et al*., 2009; Heller *et al.,* 2009; López-Aranda *et al*., 2009ab.

5.2.3 Application methods

MB or its chemical alternatives should be applied in such a manner as to provide good penetration of the soil profile for maximum contact with the pathogens or pests. The method of choice will depend on the fumigant used, whilst considering worker safety and environmental impact.

5.2.3.1. Shallow injection (Shank injection)

Mechanized injection rigs, which apply MB, MB/Pic or alternative fumigants and their combinations at depths of 15 to 30 cm in soil (called ‘shallow or shank injection’) and which are immediately sealed with tarps in strips (rows) or broadacre are most often used when applying fumigants. Fumigants may be injected into pre-formed beds or beds may be formed as part of the application process at the time of injection, covering them with plastic mulch as part of the operation. Strip application generally results in less fumigant per hectare than broad-acre application, and although may provide an opportunity for re-colonization from untreated furrows is used with excellent results in many parts of the world.

5.2.3.2. Deep injection

‘Deep injection’ at approximately 80 cm depth, which does not require plastic mulching is also used. It is carried out mainly as strip fumigation, or as an auger application to individual tree or vine holes prior to planting and replanting in deciduous orchards, vineyards and other plantations, and mainly in the USA (Browne *et al.,*2006*,* 2009).

5.2.3.3. Manual application

Fumigants can also be applied manually using simple equipment. In the case of MB, this involved pre-vaporizing the gas in a 'hot gas' method or directly from a punctured canister as a cold gas on soil that is pre-tarped with plastic mulch. The use of canisters has now been banned in many countries due to safety concerns.

The **hot gas** method is suited for small-scale operations or enclosed spaces where machinery is difficult to operate. Liquid MB from cylinders under pressure is vaporized in a heat exchanger and then dispersed under plastic covers over the top of the soil. As MB is a heavy gas, it permeates into soil. This was the main application method used in A5 countries and the predominant method used in greenhouses (glass and plastic), tobacco seedling production and potting soils in both non-A5 and A5 countries and for outdoor fumigation in A5 countries.

The **cold gas method (canisters)** is simple but often inefficient. Small steel canisters of less than 1 kg are placed under thick plastic sheets and then punctured to release the gas into soil, taking care to not damage the plastic barrier and thereby increase risk to the user. Canisters have been banned in all non-A5 countries and remain registered only in a few A5s such as China, Jordan, and Egypt.

A novel application method for 1,3-D and/or Pic is that of controlled release capsules**,** which has been developed in China. Gelatin capsules are manually placed in 15 cm deep furrows in the soil and have shown equivalent efficacy to both MB and 1,3-D/CP liquid injection treatments (Wang *et al*., 2013)

Fumigants can also be applied through drip irrigation lines. This method was sometimes used for applying MB in greenhouse crops, but is more widely used with alternative chemicals. In the US, drip application has become important for 1.3-D/Pic mixtures and emulsifiable formulations of Pic and 1,3-D followed sequentially by metham sodium. Application through drip irrigation improves fumigant distribution in the soil, allows for reduced dosages and better control of emissions, especially when combined with barrier films (Ajwa *et al*.,2002). Although drip application is economically feasible, its effectiveness over a three-year period for controlling *Macrophomina* and *Fusarium* attacking strawberries in certain high pest pressure areas in California has been questioned (Koike *et al.,* 2011; 2013, Gordon *et al.,* 2011).

5.2.4 Registration Issues in some A5 and non A5 countries

Lack of registration of some MB alternatives as well as regulatory constraints have hampered MB phase-out in some countries where MB is still being used under a critical use exemption. This section focuses on countries submitting CUNs in 2014.

5.2.4.1. Non-Article 5 Countries

Australia: The registration of methyl iodide (MI) for strawberry runners in Australia was withdrawn by Arysta Lifesciences in 2012. BOC/Linde also withdrew further funding to generate the registration data for EDN in 2010, and Nordiko decided to not pursue registration of recaptured MB. These situations have forced Australia to develop and implement a completely new research program to replace MB involving integrated soil disinfestation with combinations of existing registered fumigants. New formulations of 1,3-D/PIC (20/80 and 40/60) are being trialed in an effort to reduce phytotoxicity and yield loss occurring at higher concentrations. The new formulations are being co-applied with MITC and include post-transplant herbicide applications.

Canada: PIC100, which has been registered by PMRA, is considered the most feasible MB alternative for strawberry runners; however, Prince Edward Island (PEI) authorities have not granted a license for its use on PEI due to potential groundwater (GW) concerns. A GW study was planned with the expectation that PIC100 may be cleared for use in PEI to replace MB in 2017, however the study was halted in mid 2014. In 2011, 1,3-D was detected in PEI GW, and its license for use on strawberry runners in PEI was revoked**.**

USA: Pic alone at high rates has allowed for continued transition away from MB in California strawberries and the Party has indicated that 2016 will be the last year for MB CUE use on strawberries in California. A new MB alternative, mustard oil with allyl isothiocyanate (AITC) was registered in September 2013 on strawberries, peppers, tomatoes, eggplants, carrots, potatoes, broccoli, cauliflower, cucumber, squash, melons, asparagus and turf but not yet in California. It offers the advantage of very small buffer zone requirements compared to MB and other fumigants.

In 2014, township caps for 1,3-D in California were limited to 90,250 lbs (1X) whereas previously some township caps were 2X. The impact of this new restriction on townships with heavy use of 1,3-D on strawberries is not known at this time. Until now,PIC-Clor 60 had allowed for increased strawberry acreage to be treated with 1,3-D under the existing township caps. In December 2012 EPA implemented new soil fumigant labels providing enhanced protection for workers and bystanders. One new requirement is large buffers around treated fields where the buffer zone distance varies with the size of the treated field, the application rate, soil type and tarp impermeability. The impact of these new label restrictions is not yet known.

5.2.4.2. Article 5 Countries

Argentina: Efforts to transition away from MB used on tomatoes, peppers and strawberries in high pest pressure areas is hampered by the lack of registration of some alternatives – particularly Pic alone and dazomet.

China: Currently, small-scale ginger growers are using canisters of MB (cold gas) under a CUE. The only registered alternative is Pic, which has not provided adequate nematode control and requires longer fumigation time under low temperature conditions. The Party anticipates registration of other MB alternatives (1,3-D, dazomet, MS and DMDS) possibly by 2018.

Mexico: Preliminary research trials on strawberry and raspberry nurseries show promising results with 1,3-D/Pic, Pic/MS and MS alone. Further trials are required to assist final transition away from MB can occur.

5.3. Non-chemical alternatives

5.3.1. Grafting

Grafting has been used for almost a century in Asia to control soilborne pathogens,improve plant yield and promote plant vigor (Louws *et al*., 2010; Yilmaz *et al*., 2011; Foster and Naegele, 2013;Keinath and Hassell, 2013,2014). Commercial adoption of grafting has increased all over the world in the past 30 years (Besri 2008; Louws *et al*., 2010; Schwarz *et al*., 2010). Vegetable grafting was introduced to the

United States more than 20 years ago, and its use by commercial growers and home gardeners has steadily increased (Miles *et al*., 2013ab).

Grafting is an environment-friendly option and often a major component of IPM strategies devised to manage biotic and abiotic stresses in vegetable crops. One of its great advantages is that it can successfully control a wide spectrum of diseases such as *Fusarium, Verticilium, Pyrenochaeta, Monosporascus, Phytophthora*, *Pyrenochaeta*, *Meloidogyne*, some viruses (CMV, ZYMV, PRSV, WMV-II,TYLCV) (Louws *et al*., 2010; Ricárdez-Salinas *et al*., 2010;Yilmaz *et al*., 2011; Kousik *et al.,* 2010, 2012; Cohen *et al* 2012;Gilardi *et al.,* 2013;Erin *et al.,* 2013) and bacteria (Suchoff *et al.,* 2013).Along with reducing disease impact, grafting increases yield, improves fruit quality, promotes growth, extends production periods and crop longevity, allows for more efficient fertilizer use, and increases tolerance to soil salinity, low temperature, drought and flooding (Gisbert *et al*., 2011ab; Karaca *et al*., 2012; Çandır *et al*., 2013; Wahb-Allah**,** 2014). Moreover grafting allows for a lower plant density without compromising yield in some vegetables like tomato, watermelon and melon (Ricárdez-Salinas *et al*., 2010).

Recent studies focus on improving the tolerance of vegetables to abiotic stresses including soil salinity, drought, heavy metals, organic pollutants and low and high temperatures (Schwarz *et al.*, 2010; Colla *et al.*, 2012a; Öztekin and Tuzel, 2011, Wahb-Allah**,** 2014). Temperature fluctuations can affect rootstock resistance to nematodes (Verdejo-Lucas *et al.,* 2013) and controversial results have been reported with respect to the effects of grafting on vegetable fruit quality (Turhan *et al*.,2011, Wahb-Allah 2014, Chávez-Mendoza *et al.,* 2013, Karaca *et al*., 2012, Gisbert *et al.,* 2011ab).

Crown rot caused by *Phytophthora capsici* in various vegetables was successfully controlled with commercial bottle gourd rootstocks with resistance to this pathogen (Chandrasekar *et al*., 2012). Interspecific hybrid rootstocks restricted *F. oxysporum* f. sp. *Niveum* movement into the watermelon scion, suppressed wilt symptoms, and increased fruit yields in an infested field (Keinath and Hassell, 2014).There is evidence of pathogenic variation among some isolates of *Phytophthora* spp. affecting solanaceous crops and their rootstocks as well as new diseases or re-emerging pathogens such as *Colletotrichum coccodes* and *Rhizoctonia solani* (Giraldi *et al.,* 2014b*)*.

The best performance of grafted plants is achieved when used as a component of IPM programs combining non-chemical and chemical options (Bogoescu *et al.,* 2010, Yilmaz *et al.,* 2011). Preplant soil fumigation with 1,3-Dcombined with grafting is widely used to control root knot nematodes and soilborne diseases of different crops (Bogoescu *et al*., 2010). Soil solarisation combined with grafting significantly increased cucumber yield and reduced soilborne pathogens and nematodes in Turkey (Yilmaz *et al*., 2011). In Italy, grafting plus solarisation successfully controlled *Phytophthora capsici* on bell peppers (Morra *et al*., 2013). In Romania, metham sodium plus grafting resulted in significant yield increase and reduction in soilborne pathogens in cucumber, watermelon and tomato (Bogoescu *et al*., 2010, 2011,2014).

5.3.2. Resistant cultivars

Resistant cultivars offer an excellent option for managing soilborne diseases and nematodes in various crops particularly vegetables and strawberries (Christos *et al*., 2011; Jari *et al*., 2011; Fang *et al.,* 2012; Pérez-Jiménez *et al.*, 2012; Ogai *et al*., 2013.) In recent years, grafting resistant cultivars has provided a powerful tool to manage biotic and abiotic stresses in many types of vegetables (King *et al*., 2008; Gisbert *et. al.,* 2011ab). In addition to healthy plants, resistant cultivars achieve high quality and yields and are able to overcome adverse effects of abiotic stresses like soil salinity, drought, low and high temperatures (Öztekin and Tuzel, 2011; Colla *et. al*., 2012a, Wahb-Allah, 2014).

Although the development of resistant cultivars and rootstocks is time demanding (5 - 15 years depending on crop species) and requires substantial research, improvement programs are under way all over the world due to their usefulness and economical value (Chandrasekar *et. al*., 2012; Guan *et. al*., 2012; Oumouloud *et. al*., 2013;Fery and Thies 2011ab; Ogai *et al.,* 2013,)

New resistant cultivars to key pathogens attacking strawberries have been developed (Shaw *et al*., 2010; Fang *et al.,* 2012; Koike *et al*., 2013; Whitaker *et al*., 2012). In California, Daugovish *et al*., (2011abc) reported that outbreaks of *Macrophomina phaseolina* and *Fusarium oxysporum* have increased in recent years causing plant collapse and yield reduction. Several strawberry cultivars showed moderate resistanceto *F. oxysporum,* however all tested cultivars were susceptible to *M. phaseolina.* Fang *et al.,* (2012) evaluated yields and resistance of strawberry cultivars to crown and root diseases in Western Australia and found that cv. Festival was the most resistant to *Fusarium oxysporum* wilt, binucleate *Rhizoctonia* AG-A, *Cylindrocarpon destructans,Pythium ultimum* and *Phoma exigua* under controlled conditions. Differentlevels of resistance to various soil borne pathogens in strawberry cultivars has been reported in Spain (Pérez-Jiménez *et al*., 2012) and Korea (Lee *et al*., 2012).

Although resistant cultivars offer many advantages, certain conditions may limit their use including the appearance of new diseases, new races that overcome resistance genes, presence of a diverse range of nematodes, soil borne fungi andviruses in the same field and high pathogens pressure (Tanyolaç and Akkale, 2010; Chandrasekar, *et.al*, 2012, Villeneuve *et al.,* 2014). Individual cultivars may perform differently depending on soil type, fertilization and cultural practices (Shaw *et al*., 2010, Daugovish *et al*., 2011.)

5.3.3. Substrates

Substrates have replaced MB particularly in protected, high-cash crops demanding excellent quality, healthy plants. Although the initial investment is typically high, increased productivity and yield due to higher planting densities and improved quality generally compensate the extra costs. Several countries have developed substrate systems that are cost effective employing locally available materials (Thomas *et al*., 2011; Fennimore *et al*., 2013a).

In soilless culture, *Phytophthora cactorum* has been reported as an important threat for strawberry propagation and production, for which no reliable non-chemical control measures are available. Pathogen dissemination can be reduced by disinfecting irrigation water with slow sand filtration leading to reductions of 45-65% in disease severity. A complementary strategy to reduce damage caused by *P. cactorum* is to enhance disease suppressive properties of the soilless substrate (Evenhuis *et al.,* 2014).

Substrates are used alone or in combination with other alternatives. Substrates and compost with suppressive effects towards selected soilborne pathogens are of practical interest (Colla *et al*., 2012). Grafted plants were shown to grow more vigorously and produce higher yields when grown on substrates than when grown on soil (Marcic and Jakse, 2010).When incorporated into the substrate, biocontrol agents may play a role in suppressing soilborne diseases (Pugliese *et al*., 2014).

5.3.4. Steam

Steam disinfestation is an increasingly attractive strategy to control soilborne pathogens and weeds both in greenhouses and field crops (Gelsomino *et al*., 2010). Its use dates back as early as 1888, but in the 1960s it was substituted by cheaper chemical treatments, mainly MB (Gay *et al*., 2010). Soil steaming is very effective and is considered a valid alternative to MB for controlling soil pathogens and weeds, especially in high value greenhouse crops (Gelsomino *et al*., 2010). Steaming offers the additional advantage of posing no environmental or worker safety issues such as are associated with chemical fumigants (Fennimore *et al*., 2013).

Steam should heat the soil to a temperature of 60-80°C at 10 - 20 cm depth, depending on the target organisms.The duration and amount of steam needed to reach these temperatures will depend on various soil factors, including texture, type and moisture content, but also on the type of equipment and fuel used.

Steam disinfestation resulted in strawberry fruit yields that were comparable to those produced in fumigated soils. Additional work is in progress to evaluate efficacy in large-scale production systems in different strawberry production districts in California (Samtani *et al*., 2012; Fennimore *et al*., 2013). Further, steam may allow wider land utilization near urban areas in California, where buffer zones restrict strawberry production since fumigants cannot be applied (Fennimore *et al*., 2011).

High temperatures may result in eradication of beneficial microorganisms and result in rapid reinfestation of treated soil by soil-borne pathogens found in irrigation water, seeds or plantlets (Roux-Michollet *et al*., 2010). For this reason it is recommended to not overheat the soil, and incorporate compost or biocontrols into the soil as soon as the steaming treatment ends.

New developments of steam application methods aimed at reducing costs and extend its use on crops grown outdoors, were tested by evaluating efficacy against selected soilborne pathogens (Colla *et al*., 2012b). Development of more efficient and economic steam application equipment, currently in progress, suggests that steam is approaching wider commercial feasibility (Fennimore *et al.,* 2013b).Gilaldi *et al.,* (2014) compared the efficacy of different steaming methods (sub-surface steam injection, surface steam application by means of iron plate and sheet steaming) for controlling selected soil-borne pathogens *(Fusarium oxysporum* f. sp. *raphani*, *F. oxysporum* f. sp. *Conglutinans* and *F. oxysporum* f. sp. *basilica*) in sandy-loam soil. The steam injection system was the most efficient in terms of chlamydospore reduction.

5.3.5. Hot water

Hot water treatment is used in Japan to control *Fusarinum oxysporum*, particularly in repeated cropping systems such as celery (Fujinaga *et al.,* 2005) and involves injecting water from a portable boiler into the field. This treatment is useful for soil sterilization in protected houses for ornamental and vegetable crops. Hot water treatment at a rate of200l/ m^2 controls nematodes and root rot diseases of autumn-winter muskmelon but at very cost which has reduced its use(Gyoutoku *et al*., 2007).

5.3.6. Solarisation

Soil solarisation is a method using high temperatures produced by capturing solar energy to control soil-borne pests. The soil is heated with a plastic tarp, which is left in place for a period of time that varies according to irradiation and air temperature. When properly applied, the plastic sheets allow the sun's radiant energy to be trapped in the soil, heating the top 30 to 45 cm and killing a wide range of soilborne pests (Gamliel and Katan, 2012)
The effect of solarisation is stronger at the soil surface and decreases with soil depth. The maximum soil temperature in the field is usually 40 - 70ºC at a depth of 5 cm and 30° - 37°C at 45 cm. Although some pests may be killed within a few days, 4 to 6 weeks of exposure to the full sun during the summer is usually required to ensure control of many others (Katan and Gamliel, 2012ab)

Negative side effects observed in several cases with soil steaming and fumigation, e.g. phytotoxicity and pathogen reinfestation due to the creation of a biological vacuum, have been rarely reported with solarisation (Katan and Gamliel, 2012a; Antoniou *et al.,* 2014).

This method was initially developed in Israel in the mid seventies (Katan *et al.,* 1976), showing its effective control on *Verticilliun dahliae* of tomato and eggplant.Soil solarisation research is still very dynamic (Katan, 2014) and studies are being carried all over the world for different crops including tomatoes, tobacco, melons, peppers, strawberries, and flowers. Solarisation has been successfully used in MB phase-out initiatives for example in Egypt (Mokbel, 2013); Mexico (Muñoz Villalobos, 2013); Argentina (Mollinedo, 2013), Spain (Castillo García, 2012); Costa Rica (Monge-Pérez, 2013), Greece (Antoniou *et al.,* 2014), Turkey (Yucel *et al.,* 2014), Spain (Guerrero-Diaz *et al.,* 2014) and Italy (D'Anna *et al.,* 2014). In Italy, soil solarisation reduced infections caused by *P. lycopersici* to levels comparable to MB fumigation and better than metham sodium and metham potassium (Vitale *et al.,* 2011).Lombardo *et al.,* (2012) reported that solarisation efficiently controlled tomato soil pathogens and enhances plant growth and fruit yield. Solarisation is thus considered an effective alternative to MB in greenhouse tomato production in many countries where it is applied alone or in combination with other alternatives within IPM programs (Katan, 2014).

An interesting adaptation of solarisation where relatively small amounts of substrate can be solarized inside a "solar collector" was devised and used in Brazil to replace MB used by thousands of pot plant growers (UNEP; 2014, Ghini, 2014, Ghini *et al* 2007).

5.3.7. Biofumigation

Biofumigation is the practice of using volatile chemicals released from decomposing plant biomass to control soil borne pests, including nematodes, bacteria and fungi (Oka, 2010; Mowlick *et al.,* 2013). Numerous studies focus on the role of glucosinolates (GLSs) and cognate isothiocyanates (ITC) as bionematicides. These chemicals, containing sulfur, are released from Brassicaceae, commonly known as the ''mustard'' plant family (Argento *et al.,* 2013). The use of Brassica cover crops and their associated degradation compounds as biofumigants to manage soilborne pathogens offer vegetable growers an alternative toMB. Many pathogens attacking pepper (*Rhizoctonia solani*, *Sclerotium rolfsii*, *Pythium* spp.) have been successfully managed by biofumigation using oilseed radish (*Raphanus sativus*), 'Pacific Gold' mustard (*Brassica juncea*) or winter rapeseed (*Brassica napus*). Cover crops were disked into soil in spring and immediately covered with virtually impermeable film to reduce escape of volatile pesticidal compounds. Concentrations of isothiocyanates, the compounds primarily responsible for such pesticidal activity, were highest following incorporation of mustard with rapeseed yielding the second highest ITC concentrations, whilst radish yielded very low ITC concentrations (Hansen and Keinath, 2013).

Garlic residues were used to control root-knot nematodes in tomato, and sulfur-containing compounds might be responsible for the inhibition of *M. incognita*. (Gong *et al.,* 2013).The presence of large amounts of sulfur compounds in *Allium* species suggests that the residues of these plants may be used in soil biofumigation. The active molecules in *Allium* sp. were determined to be dimethyl disulfide (DMDS) and dipropyl disulfide (DPDS) (Arnault *et al.,* 2013).The growth stage of plants has an influence on the biofumigant potential of plant materials against soil borne pathogens (Morales-Rodriguez *et al.,* 2012). In Spain and other countries, many different types of residues are used for biofumigation with excellent results (Díez-Rojo *et al.,* 2010). This technology has been transferred to different countries and sectors for example Ecuador (Castellá-'Lorenzo *et al*, 2014).

Biofumigation and biosolarisation are used as part of IPM programs to replace MB for controlling soilborne pathogens and weeds in many crops including vegetables and ornamentals with good results. Biofumigation combined with antagonistic microorganisms provided very good control of *Phytophthora* blight of pepper plants by regulating soil bacterial community structure (Wang *et al.,* 2014). The success of this strategy is influenced by the pest complex, soil characteristics, type and availability of the soil amendment, and climatic conditions (Ozores-Hampton *et al.,* 2012; Korthals *et al.,* 2014; Morales-Rodriguez *et al.,* 2014).

5.3.8. Organic amendments

Substantial quantities of organic amendments are produced annually around the world from different sources including plant residues, animal manures, peat, compost, biosolids (sewage sludge), organic wastes from municipal yards, paper mills, timber, paper products, dairy, poultry, fish, meat and vegetable processing industries (Nunez-

Zofio *et al*., 2013; Thangarajan *et al*., 2013;Morales-Rodríguez *et al.,* 2014). Recycling these organic substances in agriculture offers several advantages such as improving plant growth, yield, soil carbon content, microbial biomass and activity, alleviating the negative effects of salinity, restoring soil fertility and suppressing soilborne pathogens (Melero-Vara*et al*., 2011; Ji *et al*., 2012; Cellier *et al*., 2014; Tartoura *et al*., 2014).Organic amendments may be pathogen and site specific (Bonanomi *et al*., 2010; Mennan and Melakeberhan, 2010), so that an organic amendment suppressive to one pathogen could be ineffective, or even conducive, to others (Michel and Lazzeri, 2010; Oka, 2010; Thangarajan *et al*., 2013).

Organic amendments are used alone or in combination with other control options such as solarisation, biosolarisation or grafting (Klein *et al.,* 2012, Koron *et al.,* 2014). Their success may vary with the location, materials used, and target pests. In Spain,Melero-Vara *et al*.,(2011) treated soil with poultry manure alone or combined with solarisation to control carnation wilt caused by *Fusarium oxysporum* f. sp. *dianthi* (Fod) in greenhouses. Results showed that the addition of poultry manure in Fod-infested soil led to better disease control than soil solarisation alone, improved carnation yield and quality, and also increased plant vigor, thus providing a satisfactory alternative to MB. In another study,soil amendments with mustard and canola cover crops for management of *Phytophthora* blight on squash provided the greatest disease reduction and increased squash yield significantly compared with the non-treated control (Ji *et al*., 2012). Nunez-Zofio *et al*., (2013) reported that application of sugar beet vinasse followed by solarisation reduced the incidence of *Meloidogyne incognita* in pepper crops while improving soil quality. In contrast, Michel and Lazzeri (2010) stated that green manures and organic amendments did not improve plant yield or corky root control in tomato.Similarly, soil amendment with a turnip cover crop was not effective for reducing yellow nutsedge growth and tuber production, and did not improve bell pepper growth and yield compared to fallow plots at any initial tuber density (Bangarwa *et al.,* 2011).Mashela *et al.,* (2013)reported that the efficacy of crude extracts of *Brassica oleracea* leaves in nematode suppression and tomato productivity was dependent on soil microbial activities.

Enhancement of disease suppression properties in soils is very important for sustainable agricultural farming systems (Postma *et al.,* 2014). A soil amendment consisting of hydrolyzed fish and fish emulsion induced suppressiveness against *F. oxysporum* f. sp. *Lycopersici* and reduced disease incidence and severity in tomato, whilst increasing plant growth. For *F. oxysporum* f. sp. *lactucae*, the two amendments inhibited microconidia germination in the substrate (Bettiol *et al.,* 2014)

The effectiveness of organic soil amendments is improved when other cultural practices that support the establishment and growth of pest suppressive soil microbial communities and promote the development of vigorous, stress-free root systems of the plant hosts are used. Crop rotation, soil solarisation, and host resistance are examples of other pest management tactics that can enhance the performance of organic soil ammendments (Chellimi *et al.,* 2014).

Composting processes, optimum compost production methods, as well as compost composition and quality parameters and application methods should be evaluated before implementing this option at the commercial level (Savigliano *et al.,* 2014).

Pugliese *et al*.,(2014) and Lodha *et al.,* (2014) reported that compost suppressiveness varies according to the type of waste used and the composting process followed.

5.3.9. Anaerobic soil disinfestation (ASD)

ASD is a biologically based, non-fumigant, pre-plant soil treatment developed to control a wide range of soilborne plant pathogens and nematodes in numerous crop production systems used for example in Japan, The Netherlands and the USA (Shennan *et al.,* 2014; McCarty *et al.*, 2014;Rosskoph *et al.* 2010;Daugovish *et al,.* 2011). In Japan, this technology is known as "soil reduction redox potential", "reductive soil disinfestation (RSD)", "biological soil disinfestation (BSD)", "or anaerobic soil disinfestation (ASD)"and is widely disseminated among vegetable growers (Shinmura 2003; Momma *et al.,* 2013).Bacterial populations in the soil are essential for an effective ASD treatment. (Hong *et al.,*2012.)

Soil treatment by ASD entails the incorporation of a labile carbon source, covering with plastic sheet and irrigating the top soil to saturation (5 cm irrigation) to create conditions conducive to anaerobic decomposition of the added C source (McCarty *et al.*, 2014). ASD is widely used in Japan and is being tested in other countries with encouraging results, but still with some inconsistencies. The feasibility of this alternative is largely impacted by moisture and the availability of an appropriate carbon source (Yilmaz *et al.,* 2011; Lombardo *et al.*, 2012; Melero-Vara *et al.*, 2012;Nyczepir *et al.*, 2012).Suppression of soil borne fungal pathogens by BSD maybe attributed to anaerobic soil conditions, high soil temperature, organic acids generated and metal ions released into soil water. BSD used in Japan consists of mixing rice or wheat bran into the soil, followed by flooding the soil with water and then covering with plastic for at least three weeks to allow microorganisms to proliferate and deplete oxygen in the soil creating anaerobic,reductive conditions to inhibit soil pathogens. Populations of soil bacteria are essential for an effective ASD treatment.

Commercial use of ASD is currently limited by cost and uncertainty about its effectiveness for controlling different pathogens across a range of environments (Shennan *et al.,* 2014; Shennan *et al.,* 2010). Its feasibility is largely impacted by moisture and availability of appropriate carbon sources (Yilmaz *et al.*, 2011; Lombardo *et al.*, 2012; Melero-Vara *et al.*, 2012; Nyczepir *et al.*, 2012).

In coastal California, an ASD treatment using rice bran was shown to be consistently effective in sandy-loam to clay-loam soils for suppressing *Verticillium dahliae* and obtaining yields comparable to a fumigant control. Economic feasibility and the need for ensuring high nitrogen concentrations still limits the commercially use of ASD (Muramoto *et al* 2014). This technology has been adopted in the Florida vegetable sector (Butler *et al.,* 2012), and in California strawberries (Shennan *et al.,* 2011). On-farm demonstrations in Tennessee are in progress (Butler *et al.,* 2012).ASD technology using diluted ethanol instead of wheat bran as a carbon source has been developed (Momma *et al.,* 2010; Kobara *et al*., 2011; 2012).

Anaerobic soil disinfestation has been studied in multiple countries for the suppression of plant pathogenic fungi and bacteria. Recent work in the US has included studies on weed control and nematode management (Rosskopf *et al.,* 2014), however Zavatta *et al.,* (2014) reported that in organic strawberry/vegetable production in coastal California, weed suppression by ASD was limited.

5.3.10. Biological control

Biocontrol agents for soilborne pathogens and root pests mainly include non-pathogenic fungi, bacteria and other antagonists. *Trichoderma* spp., *Bacillus* spp. and steptomycetes show such characteristics and can also act as plant growth promoting organisms (Babalola *et al.,*2010; Sanchez-Tellez *et al.,* 2013; Mancini *et al.,* 2014).

In Honduras, the MB replacement strategy in the melon sector includes massive applications of two strains of *Trichoderma harzianum* and one strain of *Bacillus subtilis* isolated from the Choluteca region where most of the melon production occurs,to control soilborne pathogen such as *Fusarium oxysporum* and *Monosporascus cannonballus* (Michel, 2009; Martínez *et al.,* 2010, Arias 2013). Several *Trichoderma* species, such as *T.asperellum, T. harzianum, T.polysporum, T. viride* and *T. virens* are successfullyused as biological control agents against a variety of phytopathogenic fungi (Hermosa *et al.,* 2013; Kaewchai *et al.,* 2009). Biocontrol agents can be reared and multiplied directly at farms (Arias, 2013). *Trichoderma* may be propagated on a substrate of rice hulls, bran and flour with calcium nitrate or in a liquid suspension of water, sugar molasses and calcium nitrate. *B. subtilis*is also propagated on rice or a liquid suspension of sugar and sterile molasses. Biocontrol agents are then incorporated into the soil at the pre-plant stage and throughout the cropping cycle. (Castellá-Lorenzo *et al.,* 2014;Reyes, 2013, pers. Commun; Arias, 2013)

In Italy, biological control of *Sclerotinia sclerotiorum* with*Coniothyrium minitans* is commercially used. In the USA *Streptomyces lydicus* has been registed to control some soilborne pathogens (Behal, 2000).

5.3.11. Crop rotation and inter-croping

Plant inter-cropping can be used as an efficient strategy in MB replacement programs. In China, rotations of castor-oil plant, hot pepper or crown daisy with cucumber, significantly reduced infection by *Meloidogyne incognita* (Dong *et al.,* 2012). Kokalis *et al.,* (2013) selected several cover crops for their susceptibility to invasion and galling by *Meloidogyne arenaria*, *M. incognita*, and *M. javanica* and their potential as organic amendment components in anaerobic soil disinfestation (ASD) applications. Development of ASD techniques for reducing soilborne pest populations during summer months in Florida has provided insight into some of the effects of these cover crops on root-knot nematode populations (Butler *et al.,* 2012ab).

Much research has been conducted on the use of marigolds (*Tagetes* spp.) used as a cover crop for nematode suppression and some commercial adoption of this technique has occurred. Tagetes is reportedly more effective than nematicides or soil fumigants in some cases, but can also have a negative impact on cash crop growth and yield (Cerruti *et al.,* 2010) depending on how they were used (e.g. intercrop/cover crop/soil amendment, seeding rate, time between marigold and cash crop), the cultivar, species or races of target nematodes, temperature, or age of the marigold plants. Future research should focus on developing field IPM programs that take advantage of the nematode-suppressive potential of marigold (Cerruti *et al.,* 2010).

5.4. Combination of alternatives: IPM

Pest and disease management should aim to reduce pest infestation by manipulating one or more of the biotic or abiotic components involved in the disease with minimal disturbance to the environment and natural resources, whilst managing all inoculum sources (Katan, 2014; Gamliel, 2014). Integrated pest management (IPM), is a holistic approach that in addition to effective pest control, takes into consideration environmental, social, economic and regulatory issues. The basis of the IPM approach is the combination of control methods including chemical and non-chemical options (biological,physical, cultural). Soil health, training, interactions between pesticides, risk assessments, appropriate application methods and adapting IPM to each cropping system are additional issues needing consideration (Katan, 2014; Gamliel, 2014).

In many non-A5 and A-5 countries, successful IPM programs have been implemented, which do not rely on MB or other soil fumigants and which render agricultural sectors more competitive in international markets, increasingly requiring products grown within environment-friendly standards (Castellá-Lorenzo *et al.,*2014).

In Spain, IPM programs are efficiently used in strawberry production (Chamorro *et al.,* 2014). Melero-Vara *et al.,* (2012) demonstrated that soil solarisation alone did not provide sufficient control of root-knot nematode (*Meloidogyne incognita)*, but when it was combined with raw or pelletized poultry manure, led to similar crop yields after 9 months as 1,3 D/Pic. Organic manure treatment should be applied at the start of each successive growing season.

In India, *Macrophomina phaseolina* is the most destructive soil borne plant pathogen in the arid regions causing charcoal rot in many high value crops. Combining *Brassica* amendments such as mustard residues or mustard oil cake with one summer irrigation was found effective for reducing incidence of *Macrophomina;* this effect was improved when a prolonged exposure of the soil to dry summer heat preceeded the treatment (Mawar and Lodha, 2014).

In Italy, Gilardi *et al.,* (2014a) developed a strategy to control *Fusarium oxysporum* f. sp. *conglutinans* and *F.oxysporum.*f. sp. *raphani,*causal agents of fusarium wilt of rocket and basil,by combining amendments and soil solarisation. An IPM strategy combining grafting and compost treatment to control *Phytophthora capsici*on bell pepper has also been developed (Gilaldi *et al.,* 2013).

In Poland, Chalanske *et al.,* (2014) reported that growing tomato grafted plants in fumigated soil has limited influence on the final yield when the pressure from soil-borne pests and pathogens is low.

In Turkey, Boegoescu *et al.,* (2014) reported that grafting combined with soil disinfestation with metham sodium led to significant reduction in the incidence of *Fusarium oxysporum* f. sp. *melongenae, Verticillium dahlia* and *Meloidogine incognita* on eggplant.

In USA, a soil treatment consisting of solarisation plus a wheat based organic amendment was as effective as preplant fumigation with MB in increasing peach tree survival for at least 6 years after orchard establishment (Nyczepir *et al.,* 2012). ASD plus solarisation is effective for managing plant-parasitic nematodes. Efficiency of this combination is comparable to MB for plant pathogen inoculum survival (Butler *et al.,* 2012).

5.5 Crop specific strategies

5.5.1. Strawberry fruit

Intensive cultivation of strawberries increases populations of soilborne pathogens, which often leads to soil disinfestation. In California, problems are reported in fields that were not fumigated with MB/Pic for a few years and are mainly associated with two pathogens: *Macrophomina phaseolina* and *Fusarium oxysporum* f. sp. *Fragariae* (Koike *et al.,* 2013).

A meta analysis conducted by Belova *et al.*(2012) does not support the technical superiority of MB over its alternatives, and shows that several economical and technically feasible alternatives are available for strawberries in California, in particular 1,3-D/Pic 65:35 formulation.

In Morocco,drip applied metham sodium (MS) at a dosage of 200 to 250 g /$m^2$is successfully used to control fungi attacking strawberries (*Rhizoctonia solani, Verticillium dahliae*, *Phytophthora cactorum*) and more than 40 species of weeds including C*ynodon dactylon, Chenopodium* sp*,* and *Amaranthus sp*. Yields and quality obtained with metham sodium were equivalent to those achieved with MB in the past (Chtaina and Besri, 2006; Chtaina, 2008).

In Turkey, the main soilborne pathogens of strawberry are *Fusarium oxysporum, Rhizoctonia solani* and *Macrophomina phaseolina*. Solarisation plus dazomet at a rate of 400 kg/ha was found effective for controlling diseases, nematodes and weeds in this crop, but some farmers are also adopting solarisation plus manure as a feasible option (BATEM, 2008).

In Lebanon, chemical alternatives (metham sodium and 1,3-D/Pic) and soil solarisation are widely applied with great success in many regions (UNEP/MLF/MoE/UNIDO, 2004).In Egypt, metham sodium combined with solarisation and bio-control agents is widely used by large-scale open field strawberry growers (UNIDO, 2008a).

In Chile, previous MB users are mainly adopting chemical alternatives, particularly metham sodium and 1,3-D/Pic, and in Mexico the situation is similar (UNIDO, 2008b; UNIDO, 2010)

In California, USA, fumigant use regulations have impacted the transition from MB to alternatives as previously described. Combined treatments involving steam and soil amendments like mustard seed meal (MSM), showed very favorable results in terms of yield and quality as well as weed and pathogen control. An economic analysis showed returns far exceeded costs of steam treatment (Fennimore *et al.,* 2013a). A further 5-year project is under way (Fennimore *et al.,*2013b) to facilitate the adoption of strawberry production systems that do not use MB and focus on non-fumigant alternatives (soil-less production, biofumigation, anaerobic soil disinfestation, steam). Strawberry fruit yields from substrate production were comparable to those obtained with conventional methods. Anaerobic soil disinfestation also resulted in fruit yields that were comparable to those from conventionally fumigated soils.

The increase in crown and root rot incidence, caused by *M. phaseolina* in Israel may be related to the phase-out of MB, but this pathogen is being effectively controlled with metham sodium (Zveibil *et al.,* 2012).

5.5.2. Tomato and pepper

Effective chemical and non-chemical alternatives to MB have become available for tomato and pepper crops, and MB use has been entirely phased out in all developed countries and the vast majority of developing countries (TEAP, 2014).

Chemical and non-chemical alternatives including resistant varieties, grafting, soilless cultivation, solarisation, biofumigation, biodisinfestation, ASD, biocontrols, organic amendments and steam application have been adopted alone or in combination to prevent the damages of soilborne pathogens and weeds in many countries of the world (Christos *et al*., 2011; Martinez *et al*., 2011; Yilmaz *et al*., 2011; Nunez-Zofio *et al*., 2013; Ogai *et al*., 2013; Butler *et al*., 2014; Elgorban *et al*., 2014; Martin *et al*., 2014).

In China, Ji *et al.,* (2013) indicated that Telone C-35 was an excellent MB alternative in tomato production. Its efficacy is increased if included within an IPM program.

Resistant cultivars provide an excellent option to manage soilborne diseases and nematodes in tomato and pepper as they offer various advantages including healthy plants, high-quality yields and tolerance to adverse abiotic stresses such as soil salinity, drought, low and high temperatures (Öztekin and Tuzel, 2011; Colla *et. al*., 2012a; Wahb-Allah**,** 2014). The emergence of new diseases or new races of pathogens that overcome resistance, as well as very high pest pressures may limit the use of resistant cultivars under certain conditions (Kousik *et al.,* 2010; Tanyolaç and Akkale, 2010.)

Grafting is widely adopted in the tomato and pepper sectors around the world. This technique offers various advantages as described in section 4.3.1 of this report.

Substrate production is often combined with other options like resistant cultivars, grafting and biocontrol agents, and is an effective and well established system for tomato and pepper in Northern Europe and some Mediterranean countries. As stated previously, initial costs may be high but are offset by increased productivity and yield (Marsik and Jakse, 2010; Colla *et al*., 2012b).Biocontrol agents have proven to effectively control many soilborne pathogens in substrate production systems (Pugliese *et al*., 2014).

In Spain, repeated applications of biosolarisation greatly reduced Fusarium populations (reductions greater than 72%), an effect similar to or even greater than that of MB (Martinez *et al.,* 2011). In Italy, *Pyrenochaeta lycopersici* infections were significantly reduced by solarisation, at levels comparable to MB and greater than metham sodium and metham potassium (Vitale *et al.,* 2011).In Turkey, solarisation combined with grafting considerably improved early flowering time, plant vigor, early and total yields and decreased nematode and Fusarium wilt damages in cucumber (Yilmaz *et al*., 2011). Sugar beet vinasse as a soil amendment applied before solarisation drastically decreased the incidence of *Meloidogyne incognita* in pepper crops and improved soil quality in Spain (Nunez-Zofio *et al*., 2013).Other organic materials including manure, decomposed plant materials or organic by-products from different sources to soil before solarisation increase the effectiveness of solarisation as decribed previously (Guerrero *et al*., 2010; Martinez *et al.,* 2011).

Various chemical alternatives including Pic,1,3-D, MITC, DMDS, AITC, SF, abamectin, dazomet and metham sodium are presently available to control soilborne diseases, nematodes and weeds in tomato and pepper production around the world (Wu *et al.,* 2011; Qiao *et al.,* 2012ab; Cao *et al.,* 2014). They can be used alone or in combination, or together with non-chemical options (Wang *et al.,* 2013; Mao *et al.,* 2012, 2014). Some phytotoxicity and environmental problems are associated with certain chemicals under specific conditions, as well as regulatory constraints in certain countries may limit their use. (Daugovish and Fennimore, 2011; Belova *et al.,* 2013; Devkota *et al.,* 2013).

5.5.3. Cucurbits

MB use in cucurbit crops was almost entirely phased-out in A5 countries in 2014. Since cucurbits alone amounted to about 32% of total MB consumption for controlled uses in A5 countries in 2009 (TEAP, 2010), this is an achievement worth noting.

Cucurbit grafting has gained increased interest in many countries proving economically feasible, accessible and sustainable(Louws *et al*., 2010; Schwarz *et al*., 2010; Yilmaz *et al*., 2011**).** Grafting is used to control nematodes, particularly root knot **(***Meloidogyne* spp.) in many A5 countries including Chile (Ban *et al*., 2014), China (Liu *et al*., 2014), Egypt (Amin and Mona, 2014) and Turkey (Yilmaz *et al*., 2011). Some of the rootstocks provide reasonable resistance to Fusarium wilt in melon (Ricárdez-Salinas *et al*., 2010), watermelon (Mohamed *et al*., 2012; Keinath and Hassell, 2014) and cucumber (Yilmaz *et al*., 2011), in Mexico, Egypt, USA and Turkey, respectively. Grafted watermelon plants showed significantly lower Verticillium wilt severity than non-grafted plants in the USA (Miles *et al*., 2013). Grafting increases plant growth and yield without reducing fruit quality in watermelon (Karaca *et al*., 2012; Mohamed *et al*., 2012; Çandır *et al*., 2013). Certain cucurbit rootstocks increase tolerance to soil salinity, drought, low temperature and flooding (Schwarz *et al*., 2010; Öztekin and Tuzel, 2011; Colla *et al*., 2012; Wahb-Allah**,** 2014). In Mexico, it is possible to use a lower plant density when growing grafted watermelon and melon, without any yield reduction (Ricárdez-Salinas *et al*. 2010). Suitable rootstocks of watermelon promoted plant tolerance to low potassium stress in China (Huang *et al*., 2013).

Grafting works best when used within an IPM approach. In Turkey, solarisation combined with grafting induced earlier flowering times, improved plant vigor, enhanced yield and decreased damage caused by nematodes and Fusarium wilt in cucumber (Yilmaz *et al*., 2011) In Romania, grafted plants grown on soils treated with metham sodium was successful for controlling soilborne pathogens affecting cucumber and watermelon, and significantly increased yields (Bogoescu *et al*., 2010).

Other alternatives available for cucurbit production include soil amendments such as mustard and canola cover crops, which significantly reduce damage from *Phytophthora* blight and increase yield in squash (Ji *et al*., 2012). In China, SFprovided good efficacy against root-knot nematodes (*Meloidogyne* spp.) and moderate activity against *Fusarium* spp. and weeds (*Digitaria sanguinalis*) in cucumber and tomato (Cao *et al*., 2014). Gelatin capsules of 1,3-D/Pic described previously provide another good option. (Wang *et al*, 2013).

5.5.4. Ginger

The main soil-borne pathogens of ginger are root-knot nematodes (*Meloidogyne* spp.), Pythium root rot, (*Pythium* spp.), bacterial wilt (*Ralstonia solanacerum)* and weeds, mainly nutsedge (*Cyperus rotundus*).They are aggressive pathogens that may lead to total crop loss (Anonymous, 2009). Presently, the only chemical alternative registered in China is chloropicrin (Pic), which is effective against fungal and bacterial pests but is less effective against root-knot nematodes and weeds. Low temperature and strong winds can reduce the effect of fumigation and lead to phytotoxicity. Further, the fumigation window for Pic use is short, and plant-back periods are longer than those of MB (Mao *et al*, 2014).

1,3-D has good efficacy against nematodes in ginger (Qiao, 2012) but is not registered for this crop in China. 1,3-D/Pic is thus not available, although research with this mixture shows good results. MI/Pic also showed good efficacy to control pathogens and nematodes of ginger in China, but again this mixture is not registered (Li, 2014). Non-chemical alternatives are not currently feasible due to factors such as cost, time of required application and operational requirements. For example, solarisation and bio-fumigation cannot be used in winter because of low temperatures.

A granule formulation of azoxystrobin and metalaxyl-M and a wettable powder formulation of cyazofamide are applied in Japan during the growing season for controlling ginger root rot. (Tateya, 2009; Yazuaki, 2012; Morita, 2012).

Soilless cultivation is widely used in Hawaii, USA and Malaysia (Hepperly, 2004; Yaseer, 2012).

5.5.5 Nurseries

5.5.5.1 Perennial crop field nurseries

Many types of propagation material (bulbs, cuttings, seedlings, young plants, sweet potato slips, strawberry runners, and trees) are subject to high health standards and treatments intended to provide control of pests and pathogens affecting these materials should be able to achieve an acceptable yield and quality. For propagative materials a clean root system (or clean bulbs) is essential, as it is critical to prevent the spread of economically important pests and pathogens from the nursery fields to the production fields. The required level of pest and pathogen control for propagative material must remain effective over this entire growing cycle.

In many countries, there are regulations related to nursery stock (certification), which can either specify a level of control that must be achieved or the use of approved soil treatments that are accepted for insuring a high level of control. Even if such regulations are not present,for non-certified stock, the market sets the standard that must be met. In either case, lack of a clean root system could mean a 100% loss in marketable product for the grower and in the past MB has commonly been used to meet clean propagative material standards. In some cases, sufficient data and grower experience allowed growers to transition from the 98:2 formulation of MB to 67:33 or 50:50 formulations depending on the pest or pathogen to be controlled and level of severity of the infestation (De Cal *et al.,* 2004; Porter *et al.,* 2007). Research trials, indicate that some alternative fumigants and combinations (such as 1,3-D/Pic) provide control comparable to MB under specific circumstances (Hanson *et. al.*, 2010; Schneider *et.al.*, 2008; Schneider *et al.*, 2009ab; Stoddard *et al.*, 2010;Walters *et al.*, 2009). As these materials meet the requirements for efficacy and consistency,regulatory entities incorporate them into the lists of approved certified nursery soil treatments (McKenry, 2011). For example,the California Department of Food and Agriculture (CDFA) approved the use of 1,3-D or methyl iodide as a certified nursery stock soil treatment for certain crops under specific conditions (CDFA, 2009). Although the latter is not available, 1,3/D offers an alternative to MB for the crops involved.

An alternate approach,where economically feasible and an acceptable product can be obtained, i.e., root system of acceptable size and quality is to use soil-less substrate production systems.

Production of high health propagative materials remains a significant challenge in some sectors (ie strawberry runners) as Parties transition away from MB (Zasada *et. al.*, 2010). The consequences of failed treatment not only impact the propagative material, but can also jeopardize the performance of MB alternatives in the fruiting fields.

5.5.5.2. Current commercial use status

The EU phased out MB in nursery production between 1992 and 2007 (EC Management Strategy, 2009). Chemical alternatives in commercial use for this purpose include dazomet, metham sodium, and 1,3-D (with restrictions as stated previously). Non-chemical alternatives include substrates, grafting, resistance, steam, and crop rotations. Japan phased out MB in nurseries in 2005. Alternatives in commercial use include dazomet, chloropicrin, 1,3-D, and MITC (Tateya pers. comm., 2010). MB is used in the US to meet certified nursery regulations (this use is allowed in the US under the QPS exemption). Alternatives in commercial use for nurseries include chemical (1,3-D, Pic, metham sodium) and non-chemical options (substrates, resistant varieties,steam) alternatives (CDFA, 2009).

In A5 countries, certified plant materials are produced without MB; for example, substrates are used for certified citrus and banana propagative materials in Brazil (Ghini, pers. comm., 2014); grape, pear, apple, and citrus propagative materials are produced in Argentina without MB (Valeiro, pers. comm., 2010).

5.5.5.3 Strawberry nurseries

MB was the fumigant of choice for over 60 years in this industry, because it provided nursery stock of high plant health to meet the requirements of the fruit industry. This may have been to meet certification or standards required by export markets, and also assisted the industry to avoid litigation from strawberry growers for movement of diseases. A recent publication gives an excellent overview of the situation for the strawberry fruit and nursery industries worldwide (Lopez- Aranda, 2012).

A single strawberry runner can expand to several million runners by year five of the runner production system, so the potential impact of spreading a pest or disease is tremendous. For this reason, few alternatives to MB are considered suitable. MI/Pic mixtures, 1,3-D/Pic and Pic alone in some situations, substrate production of plug plants and to a lesser extent where regulations prevent the use of the above alternatives, MITC generators (metham sodium and dazomet) are the alternatives being adopted.

In 2014, MB is still used in three non-A5 Parties either as a critical use (Australia, Canada) or under a QPS exemption (USA). A number of A5 Parties (Argentina, Chile, China, Egypt, Mexico,Vietnam and others) used MB for strawberry runner production and several have already phased out MB in strawberry nursery industries (e.g., Brazil, Lebanon, Morocco, Turkey). Mexico is continuing use in 2015 and under a critical use exemption, but trials with alternative fumigants (1,3-D/Pic, metham sodium) are giving encouraging results.

In Australia, the northern production region fully transitioned in 2009 to mixtures of 1,3-D/Pic and Pic alone, however in the cooler southern regions in heavy soil types these alternatives are phytotoxic causing losses of up to 40%, or are ineffective and no alternatives have been adopted except for the use of substrate production of foundation stock. Of the alternatives being evaluated methyl iodide was being considered by Australia as a one-to-one replacement, but registration is no longer being sought (Mattner *et al*., 2010).

Alternative fumigants deliver similar fruit yields to MB/Pic, but the incidence of diseases caused by previously obscure pathogens, such as *Fusarium* spp. and *Macrophomina phaseolina*, has increased.Certification authorities do not approve the use of substitute fumigants (1,3-D/Pic, Pic, dazomet and metham sodium) for runner production. The industry does, however, produce its early generations of runners using soil less culture, which reduces the need for disinfestation with MB/Pic. This system is not economically feasible for later generations because runner prices would need to increase by more than 500% to make them viable. Current research is investigating the combined use of low-rate fumigants and herbicides for soil disinfestation in the runner industry, with the aim of reducing the risk of crop phytotoxicity from individual products (Mattner *et al.,* 2014).

In Canada in 2008, several regions transitioned to alternatives mainly Pic alone, however owing to its lack of registration in Prince Edward Island the request for a critical use continues. Canada is awaiting an outcome for registration of Pic alone, but new studies are still needed to validate that there are no ground water contamination risks associated with its use. Substrate production appears suitable for at least a proportion of the runner chain production in these countries (i.e., nuclear, foundation and possibly some of the mother stock). This technique has been adopted widely in higher latitude regions as a means to produce runners for the shorter season northern markets, but the altered physiology of plug plants and cost of capital structures has been a limitation to date for the production of runner plants for performance over the long production seasons (6-8 months) presently given by existing runners produced with MB for temperate markets.

In the EU (France, Italy, Poland, Spain), growers are using improved application techniques for old fumigants, such as metham sodium and dazomet to grow runner plants (Lopez Aranda, 2012) in preference to moving to substrate production. In these countries, national permits can be granted for emergency use of 1,3-D/Pic use annually, however the industries are uncertain of the future use of many alternatives (Lopez- Aranda, 2012).

In some countries where MB has been phased-out, there have been market shifts where growers may produce their own plants (e.g.Japan) or where industries import runners produced in other countries (e.g., Moroccan growers import runner plants from Spain and substrate plants from France). In Turkey, the industry presently uses solarisation and metham sodium treatment.

5.6. Key chemical and non-chemical strategies adopted in several key MB user countries that have now completely phased out

As part of this assessment report, a number of countries were contacted to provide an estimate of the main chemical and non chemical alternatives that had been adopted as of 2014 in the major sectors which had previously used methyl bromide. Responses were received from technical experts in France, Italy and Japan.

Additionally several published reports have reviewed the adoption and/or effectiveness of alternatives in regions where methyl bromide has been completely phased out, such as SE USA (Noling, 2014; Vallad *et al*, 2014) and Spain (Lopez Aranda, 2012; Lopez Aranda *et al*, 2009a,b).

TABLE 5-1. CHEMICAL AND NON-CHEMICAL ALTERNATIVES[A] ADOPTED AND USED IN 2014 TO COMPLETELY REPLACE PREPLANT SOIL USE OF MB IN FRANCE

Sector	MB used in past (t)	Alternatives[a] used in 2014 and adopted to completely replace preplant soil use of MB in France	
		Chemical	Non-chemica
Carrots	10	Dazomet (100%)	
Cucumber	60	1,3-D and dazomet	Grafting, soil less
Cut-flowers	75	Metham/dazomet alone or combined with solarisation	Soil less. soil solarisation
Forest tree nursery	10	Metham/dazomet (100%)	
Melon	10	1,3 D and metham sodium	Grafting - rotation
Orchard replant	25	Metham sodium (80%) Dazomet (20%)	rotation
Pepper	27.5	Metham sodium (70%) Dazomet (30%)	Rotation -green manure
Strawberry fruit	90	Metham 80 %, Dazomet 20 %	Soil less systems
Strawberry runners	40	Metham sodium 90 % Dazomet 10 %	
Tomato	135	Metham (50%), 1,3 D (30%), dazomet (20%)	Grafting, soil less
Eggplant	27.5	Metham sodium and dazomet	Grafting , crop rotations

[A]Proportions shown refer to the breakdown for the chemical fumigants only

TABLE 5-2. CHEMICAL AND NON-CHEMICAL ALTERNATIVES[A] ADOPTED AND USED IN 2014 TO COMPLETELY REPLACE PREPLANT SOIL USE OF MB IN ITALY.

Sector	Maximum MB amount requested for CUNs	Alternatives[a] used in 2014 and adopted to completely replace prepplant soil use of MB in Italy	
		Chemical	Non-chemical
Tomato protected	1300	1,3-D/Pic . 1,3 D + Rootstocks, 1,3-D and Metham 35%, Metham or dazomet 25%	Resistant rootstocks 35% Soilless 5%
Cut flowers (protected)	250	1,3-D/Pic 30%; Metham/solarisation 20%	Soilless 50%
Eggplant (protected)	280	Non fumigant nematicides + Rootstocks 30%	Rootstocks 65%, Soilless 5 %
Eggplant (protected - other)	280	Non fumigant nematicides + Rootstocks 30% Metham 35 %	Rootstocks 20% Soilless 5%
Watermelon (protected)	180	Non fumigant nematicides + Rootstocks 20%	Rootstocks 80 %
Pepper (protected)	220	Metham 40% Dazomet 5% Rotation with fumigated crops 35%	Rootstocks 5% Solarisation 10% Soilless 5 %
Strawberry Fruit (Protected)	510	1,3-D/Pic 50% Pic 10% Dazomet 20%	Solarisation 10%
Strawberry Runners	100	Metham 20%, 1,3-D/Pic 75%, Dazomet 5%	

[A]Proportions shown refer to the breakdown for the chemical and non-chemical treatments

TABLE 5-3. RESTRICTIONS ON THE USE OF CHEMICAL FUMIGANT ALTERNATIVES IN ITALY. SIMILAR RESTRICTIONS ARE PRESENT IN OTHER MEMBER STATES OF THE EU

Chemical alternative	Restrictions on Use
Chloropicrin	Since June 2013 chloropicrin is only allowed under an emergency use (120 days) only for tomato, strawberry, ranunculus and anemone
1,3-D	Is admitted only for emergency uses (120 days) only for carrot, strawberry, melon and tobacco
Dazomet	Registered but legally only allowed once every 3 years in the same field
Metham Sodium	Registered for essential uses (that do no include strawberry) until 31/12/2014. After 01/01/2015 it will be admitted in open field at a reduced rate only with plastic.

TABLE 5-4. CHEMICAL AND NON-CHEMICAL ALTERNATIVES[A] ADOPTED AND USED IN 2014 TO COMPLETELY REPLACE PREPLANT SOIL USE OF MB IN JAPAN FOR THE CRITICAL USES. IN THE PAST, JAPAN WAS ONE OF THE LARGEST USERS OF MB FOR SOIL FUMIGATION. TE SECTORS ABOVE WERE DIFFICULT SETORS WITH UNIQUE ISSUES GLOBALLY.

Sector	MB requested for CUNs in 2005(t)	Alternatives used in 2014 and adopted to completely replace preplant soil use of MB in Japan		Main Target disease
		Chemical	Non Chemical	
Cucumber	88.3		1. Roots removed from growing in soil composting root debris, cattle manure and soil aeration 2. Bio-degradable pots to prevent root contact with virus in soil. 3. Removal of diseased plants	Kyuri green mottle mosaic virus; KGMMV
Ginger – field	119.4	1) 1,3 D/Pic, Pic alone, dazomet and dazomet & Pic. 2) Pesticide mixtures on rhizomes incl. azoxystrobin and metalaxyl M, cyazofamid, propamocarb hydrochloride liquid 3) Herbicides for weeds. eg. trifluralin, sethoxydim and glufosinate-ammonium	1. Disease free rhizomes 2. Infected plant debris humified by irrigation and cultivation. plowing 3. Hand weeding for weeds	Pythium zingiberis (Root rot disease)
Ginger – protected	22.900	2) and 3) above.	1. Disease free rhizomes 2. Solarisation (3 wks) treatment by double mulching on the soil surface and on the tunnel	Pythium zingiberis (Root rot disease)
Melon	194.100	1,3-D/Pic to control Monosporascus cannonbollus and nematodes	1. Biocontrol with attenuated virus vaccine of SH33b to control CGMMV 2. Biocontrol with resistant strain from respective production region to control MNSV	M.cannonbonematodes, Green Mottle Mosaic Virus (CGMMV), Necrotic Spotted Virus (MNSV)

Sector	MB requested for CUNs	Alternatives used in 2014 and adopted to completely replace preplant soil use of MB in Japan		Main Target disease
Peppers (green and hot)	189.9		1. Biodegradable pots and soilless media to avoid soil contact and plant damage. 2.ELISA used to predict soil population levels. 3.Attenuated virus vaccine of AVP08 to control virus disease.	Pepper Mild Mottle Virus (PMMoV)
Watermelon	126.3		1. Biodegradable pots and soilless media to avoid soil contact and plant damage 2. Soilless bags 3. Paper pots 5. Crop rotation	Cucumber Green Mottle Mosaic Virus (CGMMV)
Fumigants generally registered for crops above		Chloropicrin, dazomet, 1,3-dichloropropen, mixture of chloropicrin and 1,3-dichloropropene, mixture of 1,3-dichloropropene and methyl isothiocyanate, carbam sodium.		

5.7. Remaining and emerging Challenges

5.7.1 Non-Article 5 Parties

The key alternatives, Pic, 1,3-D and MI are subject to regulations affecting their uptake for the remaining uses of MB. In some countries,Pic is still not registered while registration of MI is generally no longerpursued.

Methods that avoid the need for fumigation (e.g. substrates, grafting, resistant varieties, solarisation, ASD) continue to expand worldwide and these technically feasible technologies become more cost effective every year. Continuous review of the economics of these technologies is required to support evaluation of critical use nominations.

Nursery uses are the most significant remaining use for MB worldwide and more studies are required to characterize the risks imposed by the use of alternatives in these industries.

MB continues to be classified differently for nursery applications by several Parties despite the target pests and crops being similar in several countries. Canada supplied a useful summary of their interpretation of this use (Canada CUN, 2012, p.19). There is an emergence of new or re-emergence of previously controlled pathogens in fields that have used MB alternatives for a few years. Examples include *Macrophomina* and *Fusarium* on strawberry.

5.7.2. Article 5 Parties

Developing countries have moved towards achieving the final phase-out of MB by 1st January 2015 as set by the Montreal Protocol. In many A5 countries, this phase out was achieved before the deadline, mainly with support from MLF-funded investment projects and in some cases through projects funded directly by A5 and non-A5 Parties through bilateral cooperation, and/or agricultural producers. The projects identified many economically and technically feasible alternatives, both non-chemical and chemical, which are as efficient as MB. Combinations of alternatives were generally encouraged as a sustainable, long-term approach for replacing MB. This has often implied that growers and other users change their approach to crop production or pest control including investments and training (which the projects normally support). Early phase-out of MB has proven beneficial to A5 parties in many instances, by improving production practices, increasing the competitiveness of certain agricultural products in international markets and training large numbers of growers, technical staff and other key stakeholders.

Some challenges persist, for example controlling bacterial diseases and nematodes affecting ginger in China, as well as complete adoption of alternatives for strawberry and raspberry runners in Mexico and possibly other countries.

Further analysis on challenges encountered by A5 Parties to complete and sustain MB phase-out is found in Chapter 7 of this report.

5.8 References

Abou Zeid, N.M. and Noher, A.M. (2014). Efficacy of DMDS as methyl bromide alternative in controlling soil borne diseases, root-knot nematode and weeds on pepper, cucumber and tomato in Egypt. Acta Hort. (ISHS) 1044:411-414

Ajwa H. A., Klose S., Nelson S. D., Minuto A., Gullino M. L., Lamberti F., Lopez Aranda J. M. (2003). Alternatives to methyl bromide in strawberry production in the United States of America and the Mediterranean region.Phytopathol.Mediterr. 42, 220-244.

Ajwa H.A, and Mona O. (2013**).** Allyl Isothiocyanate and Dimethyl Disulfide for Strawberry Production, Procceedings of the annual international research conference on methyl bromide alternatives and emission reduction. San Diego, California, Nov 4-6, 3

Ajwa H.A, Trout, T, Mueller, J, Wilhelm, S, Nelson, S.D., Soppe, R., Shatley, D.(2002). Application of alternative fumigants through drip irrigation systems .*Phytopathology*, 92, 1349-1355.

Ajwa H.A., Trout T. (2004). Drip application of alternative fumigants to Methyl Bromide for strawberry production. HortScience 39, 1707-1715.

AKIB 2013. Sektörel Bazında Aralık 2013 İhracat Verileri. http://www.akib.org.tr/tr/ihracat-ihracat-istatistikleri.html

Allan M. and Leon C. (2013). IRF135, allyl isothiocyanate (AITC) regulatory and development update. In: 2013 Annual International Research Conference On Methyl Bromide Alternatives And Emissions Reductions, San Diego.

Alpizar Y.A., Boonen B., Gees M., Sanchez A., Nilius B., Voets T., Talavera, K. (2014). Allyl isothiocyanate sensitizes TRPV1 to heat stimulation. Pflugers Archiv-European Journal of Physiology,466, 507-515.

Amin AW, Mona A.W. (2014) .Protecting cucumber from *Meloidogyne incognita* using graft onto resistant cucurbit rootstocks and antagonistic marigold as an alternative to nematicide. *Pakistan Journal of Nematology* 32(1), 51-58.

Anonymous, (2009). Australia Ginger Growers Association Inc. The Australia ginger industry, overview of market trends and opportunities. The State of Queensland, Department of Employment, Economic Development and Innovation

Antoniou, P.P., Tjamos E.C. and Giannakou J.O. (2014). low-cost and effective approaches of soil disinfestation of plastic house or open field crops in Greece. Acta Hort. (ISHS) 1044:29-41

Argento, S. Raccuia, S. A. Melilli, M. G. Toscano, V. Branca, F. (2013). Brassicas and their glucosinolate content for the biological control of root-knot nematodes in protected cultivation. Acta Horticulturae; 2013. 1005:539-544.

Arias E. (2013). Eliminación total de bromuro de metilo en Honduras. Presentación durante la Reunión de la Red Latinoamericana de Oficiales de Ozono, Kingston, Jamaica, Octubre 2013.

Arnault I., Fleurance C., Vey F., Du Fretay G., and Auger J., (2013).Use of Alliaceae residues to control soil-borne pathogens. In: Industrial Crops and Products, 49, 265-272.

Ashworth D, Van Wesenbeeck I., Stanghellini M, (2013).Effect of Co-formulation of 1,3-D and Chloropicrin on Emission from Soil. Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2013, San Diego, California

Avato P., D'Addabbo T., Leonetti P., Argentieri M.P. (2013). Nematicidal potential of Brassicaceae. Phytochemistry Reviews 12, 791-802.

Avilés M., Castillo S., Bascon J., Zea-Bonilla T., Martín-Sánchez P.M., Pérez-Jiménez R.M. (2008) First report of *Macrophomina phaseolina* causing crown and root rot of strawberry in Spain. Plant Pathology 57, 382.

Avilés M., Castillo S., Borrero C., Castillo M.L., Zea-Bonilla T., Pérez-Jiménez R.M. (2009).Response of strawberry cultivars: 'Camarosa', 'Candonga' and 'Ventana' to inoculation with isolates of *Macrophomina phaseolina*. ActaHorticulturae, 842, 291-294.

Babalola O.O. (2010). Beneficial bacteria of agricultural importance. In: Biotechnology letters, 32 (11), 1559-1570.

Ban S G, Katja-Žanić K, Dumičić G, Raspudić E, Selak G V, Ban D. (2014). Growth and yield of grafted cucumbers in soil infested with root-knot nematodes. *Chiılean Journal Of Agricultural Research* 74(1), 29-34.

Bangarwa S.K., Norsworthy J.K., Gbur E.E. (2012). Allyl Isothiocyanate as a methyl bromide alternative for weed management in polyethylene-mulched tomato. Weed Technology26, 449-454.

Bangarwa, S. K.Norsworthy, J. K.Mattice, J. D. Gbur, E. E. (2011). Yellow nutsedge interference in polyethylene-mulched bell pepper as influenced by turnip soil amendment.*Weed Technology*. 25: 3, 466-472.

Barres M.T., Bello A, Jordá C, Tello J.C., (2006). La Eliminación del Bromuro de Metilo en la Protección de Cultivos como Modelo Mundial para la Conservación del Medio Ambiente. MAPA, Madrid, 515 pp.

Barros A. F., Campos V. P., da Silva J.C.., Pedroso M. P., Medeiros F.H.., Pozza E.A., and Reale A.L., (2014). Nematicidal activity of volatile organic compounds emitted by Brassica juncea, Azadirachta indica, Canavalia ensiformis, Mucuna pruriens and Cajanus cajan against Meloidogyne incognita. In: Applied Soil Ecology, 80, 34-43.

BATEM, 2008. Phasing out methyl bromide in Turkey / Final report156 pp

Behal V. (2000).Bioactive products from *Streptomyces.* Adv. Appl. Microbiol. 47:113-156.

Bello A, Díez Rojo MA, López Pérez JA, Castro I, Gallego A. (2011). Biodesinfección de Suelos. Sociedad Española de Agricultura Ecológica (SEAE), Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid.(http://vimeo.com/18675250)

Bello A, Díez Rojo MA, López Pérez JA. (2013). Biodesinfección de suelos, investigación participativa y desarrollo rural. Cambio climático, destrucción de la capa de ozono. XXI Jornadas Técnicas Estatales SEAE. Desarrollo Rural, Innovación Agroecológica y Agricultura Ecológica en la PAC. Alcalá de Henares, Madrid, 26-27 septiembre, 15 pp.

Bello A, González JC. (2012). Agroecología y Complementariedad Agraria. 250 pp. http://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2012/libro-agroecologia-bello/libro-agroecologia-bello-sec.pdf

Bello A, Jordá C, Tello JC.(2010). Agroecología y Producción Ecológica**.** CSIC, Catarata, 77 pp.

Bello A, Porter I, Díez Rojo MA, Rodríguez Kabana R. (2008).Soil biodisinfection for the management of soil-borne pathogens and weeds.*3rd Int. Biofumigation Symposium*, 21 – 25 Jul., CSIRO Discovery Centre, Canberra, 35 p.

Belova A., Narayan T Olkin I.,,(2013) .Methyl bromide alternatives for strawberry and tomato pre-plant uses: A meta-analysis. *Crop Protection*, *54*, ,*1-14*

Besri M. (2008). Cucurbits grafting as alternative to methyl bromide for cucurbits production in Morocco. Proceedings MBAO Conference, Orlando (FL). 60,1-5pp.

Bettiol, W., Forner, C. and Mattos, L.P.V. (2014). Development of suppressiveness to *Fusarium oxysporum* in container media and soil amended with fish emulsion and fish hydrolyzed. Acta Hort. (ISHS) 1044:133-138

Bettiol, W., Rivera, M.C., Mondino, P., Montealegre, J.R., Colmenárez, Y.C. (2014).Control biológico de enfermidades de plantas en America Latina y el Caribe. Facultá de Agronomia, Montevideo. Uruguay. 404 p. http://portal.fagro.edu.uy/index.php/intensific-agr/file/367-control-biologico-de-enfermedades-de-plantas-en-america-latina-y-el-caribe.html

Bogoescu M., Doltu M., Sora D., Tanasa N. (2010). Greenhouse grafting cucumber crop - Methyl bromide alternative in Romania.*Acta Horticulturae*, 883, 129-134.

Bogoescu M., Doltu M., Lordache B., Vintila M., Sora D., Mohora A.(2011). The grafting tomatoes crop an alternative for vegetable growers. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca*.Horticulture 68, 215-221.

Bogoescu, M., Doltu, M. and Sora, D. (2014).Prevention and control of soilborne diseases and nematodes in eggplants crop by grafting plants combined with soil fumigation. Acta Hort. (ISHS) 1044:331-336

Bonanomi G., Antignani V., Capodilupo M., Scala F. (2010). Identifying the characteristics of organic soil amendments that suppress soilborne plant diseases. *Soil Biology and Biochemistry*, 42, 136-144.

Browne G., Holz B., Upadhyaya S., Lampinen B., Doll D., Schmidt L., Edstrom J., Shafii M., Hanson B., Wang B., Gao S., Klonsky K. (2009).Integrated pre-plant alternatives to methyl bromide for almonds and other stone fruits.Annual International Conference on Methyl Bromide Alternatives and Emission Reductions,Orlando, Florida USA.

Browne G.T., Connell J.H., Schneider S.M. (2006). Almond replant disease and its management with alternative pre-plant soil fumigation treatments and rootstocks. Plant Disease, 90 (7), pp. 869-876.

Bull D. L, Ivie G W., MacConnell J. G, Gruber V. F, Ku Chia C., Arison B. H, Stevenson J. M, Vanden H. William J.A (1984) Fate of avermectin B1a in soil and plants. Journal of Agricultural and Food Chemistry 32. (1):94-102.

Butler D, Kokalis-Burelle N. Muramoto J., Shennan C., McCollum T. Rosskoph E. (2012a) .Impact of anaerobic soil disinfestation combined with soil solarisation on plant-parasitic nematodes and introduced inoculum of soilborne plant pathogens in raised-bed vegetable production. Crop Protect. 39, 33-40

Butler D., Inwood E., McCarty G., Sams C..Wszelaki A., Dee M., Ownley B., Kokalis-Burelle N. Rosskopf E. (2012b). Optimizing anaerobic soil disinfestation for Tennessee.Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, Maitland, Florida USA.

Butler, D.M., Rosskopf, E.N., Kokalis-Burelle,N., Albano, J.P., Muramoto, J., and Shennan, C. (2012c) .Exploring warm-season cover crops as carbon sources for anaerobic soil disinfestation (ASD). Plant and Soil ,355,149-165.

Butler D. M., Kokalis-Burelle N., Albano J. P., McCollum T. G., Muramoto J., Shennan, C., Rosskopf E. N. (2014). Anaerobic soil disinfestation (ASD) combined with soil solarisation as a methyl bromide alternative: Vegetable crop performance and soil nutrient dynamics. *Plant and Soil*, 378, 365-381.

Canada Critical Use Nomination (2012). CDN01 CUN14. Soils Strawberry Runners PEI. Quarantine and Pre-shipment: Page 19

Çandır E.,Yetişir H., Karaca F., Üstün F. (2013). Phytochemical characteristics of grafted watermelon on different bottle gourds (*Lagenariasiceraria*) collected from the Mediterranean region of Turkey. *Turkish J Agriculture and Forestry* 37, 443-456

Candole B.L., Csinos A.S., Wang Q. (2007). Concentrations in soil and efficacy of drip-applied 1,3-D+chloropicrin and metham sodium in plastic-mulched sandy soil beds Crop Protection 26,1801–1809

Cao A. (1999) The new alternative of methyl bromide--avermectin. In: Research Progress in Plant Protection and Plant Nutrition China Agriculture Press, pp 327-328.

Cao A., Guo M., Yan D., Mao L., Wang Q., Li Y., Wang P. (2014). Evaluation of sulfuryl fluoride as a soil fumigant in China. Pest Management Science 70, 219-227.

Cao Y. (1994) Control of cucumber root knot nematode by using avermectin 1.8EC (in Chinese).Chinese Agricultural Science Bulletin 10:16-18.

Carabedian H., Gundy S.D. (1983) Use of avermectin for the control of *Meloidogyne incognita* on tomatoes. Journal of Nematology 15 (4):503-510.

Castellá-Lorenzo, G., Savigliano, R. and Pizano, M. (2014). Breaking the bondage to methyl bromide in agriculture – UNIDO experience. Acta Hort. (ISHS) 1044:281-287

Castillo García J., Amaya Uribarri G., Astiz M., Sádaba Díaz de Rada S., (2012). Guía de biofumigación y solarización de suelos en invernadero; Revista Navarra Agraria, Spain; Nº 190, 2012, págs. 21-22

Castro Lizazo I, Díez Rojo MA, López Pérez JA, Díaz Viruliche L, Bello A.(2011). Biodesinfección de Suelos en Producción Ecológica.Dossier SEAE. Valencia. 56 pp. http://www.agroecologia.net/recursos/publicaciones/dossiers/dossier-biodesinfeccion.pdf

CDFA (2009).California Department of Food and Agriculture.http://www.cdfa.ca.gov/phpps/PE/Nursery/pdfs/NIPM_7.pdf

Cerruti R., Koon-Hui W., Ploeg A.,McSorley R. (2010) .Using marigold (*Tagetes* spp.) as a cover crop to protect crops from plant-parasitic nematodes. *Applied Soil Ecology*, *Volume 46, Issue 3*, *307-320*

Chałańska, A., Ślusarski, C., Uliński, Z., Meszka , B., Sobiczewski, P., Malusá , E. and Ciesielska, J. (2014). The effectiveness of grafting and soil fumigation on the performance of greenhouse tomatoes. Acta Hort. (ISHS) 1044:263-268

Chamorro, M., Domínguez, P., Medina, J.J., Miranda, L., Soria, C., Romero, F., López Aranda, J.M., Guzman, C. and De los Santos, B. (2014). Chemical and non-chemical soil fumigation treatments for strawberry in huelva (spain). Acta Hort. (ISHS) 1044:275-279

Chandrasekar S.K., Donahoo R D., Hassell, R. (2012).Resistance in watermelon rootstocks to crown rot caused by*Phytophthora capsici. Crop Protection*39, 18–25

Chávez-Mendoza C., Sánchez E., Carvajal-Millán E., Muñoz-Márquez E.,Guevara-Aguilar A. (2013). Characterization of the nutraceutical quality and antioxidant activity in bell pepper in response to grafting.*Molecules*, 18, 15689-15703

Chellemi, D.O., Noling, J.W. and Sambhav, S. (2014). Organic amendments and pathogen control: Phytopathological and agronomic aspects. Acta Hort. (ISHS) 1044, 95-103

Chow E. (2009). An update on the development of TIF mulching films.Proc. 2009 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions.San Diego, Oct 29-Nov 1.

Christos I. R,, Ebrahim M. K., Naved S. (2011). Response of local and commercial tomato cultivars and rootstocks to *Meloidogynejavanica*infestation *Ausralian Journal of Crop Science* 5(11),1388-1395

Chtaina N., (2008a). Phase out of methyl bromide in the cut flower and banana production. UNIDO project TF/MOR/00/001 contract (ONUDI/ Institute of Agronomy and Veterinary medicine**,** Rabat Morocco) N° 2002/089. Final report, December 2008, 64 pp

Chtaina N., (2008b). Phase out of methyl bromide in soil fumigation in strawberry production. UNIDO project MP/MOR/00/164 contract (ONUDI/ Institute of Agronomy and Veterinary medicine**,** Rabat Morocco) N° 2001/261. Final report, 2008., 80pp

Chtaina N., 2005. Les fumigants nematicides à base du 1,3 dichloropropène, comme alternative au bromure de méthyle sur bananier. Pack info N° 24: 19-20

Chtaina N., Besri M., (2006). Case Study 26.: Morocco-Phase out of methyl bromide in the strawberry, banana and cut flower in Morocco. 2006 assessment report of the methyl bromide technical option committee (MBTOC) .UNEP, 424-427, 453 pp.

Cohen R., Omari N., Porat A., Edelstein M., (2012). Management of *Macrophomina* wilt in melons using grafting or fungicide soil application: Pathological, horticultural and economical aspects .*Crop Protection*, *35*, *58-63*

Colla G., Rouphael Y., Rea E. (2012a). Grafting cucumber plants enhance tolerance to sodium chloride and sulfate salinization. *Scientia Horticulturae* 135, 177–185.

Colla P., Gilardi G., Gullino M. L. (2012b). A review and critical analysis of the European situation of soilborne disease management in the vegetable sector.*Phytoparasitica* 40, 515-523.

Colla, P., Garibaldi A. and Gullino M.L. (2014).consequences of European pesticide policies enforcement in soil disinfestation sector . Acta Hort. (ISHS) 1044:363-366

Culpepper S., Sosnoskie L., Rucker K., Tankersley B., Langston D. (2008). DMDS or the 3-Way: Which is moreeffective in Georgia? Annual Int. Research Conf. on Methyl Bromide Alternatives and EmissionsReductions, 11-14 Nov, Orlando (Fl), 20-1, 20-5.

Curto G., Dongiovanni C.,Sasanelli N., Santori A. and Myrta A.(2014). Efficacy ofdimethyl disulfide (DMDS)in the control of the root-knot ncmatocle .*Meloidogyne incognita* and the cyst nematode Heterodera carotae on carrot in field conditions in Italy. Acta Hort. 1044:405-410.

DAFNP, (2009). Department of Agriculture and Forestry of Nagasaki Prefecture (2009) Establishment of standard technology on strawberry production.Nagasaki Standard Technology of Agriculture and Forestry.

D'Anna F., Iapichino G., D'Anna E. (2014). Effects of soil solarisation with different plastic films on yield performance of strawberry protected plantations in Sicily. Acta Horticulturae; (1015):53-58.

Daugovish O.,Fennimore S. A. (2011a). Non-Fumigant Alternatives for managing *Macrophomina phaseolina* and *Fusarium oxysporum* in California strawberry.http://ashs.confex.com/ashs/2011/webprogram/Paper7280.html

Daugovish O., Koike S., Gordon T., Ajwa H., Legard D. (2011b). Fumigant and strawberry variety evaluations in *Macrophimina phaseolina* and *Fusarium oxysporum* infested fields. International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. http://mbao.org/2011/Proceedings/10

Daugovish O., Muramoto J,, Shannon C., Bolda M., Koike S. (2011c). Anaerobic soil disinfestation for southern California strawberries. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, San Diego, California USA.

De Cal, A., Martínez-Terceno, A., López-Aranda, J.M. and Melgarejo P. (2004). Alternatives to methyl bromide in Spanish strawberry nurseries.*Plant Disease* 88(2): 210-214.

Devkota P., Norsworthy J.K., Rainey R. (2013). Comparison of Allyl Isothiocyanate and Metham Sodium with Methyl Bromide for Weed Control in Polyethylene-Mulched Bell Pepper. Weed Technology, 27, 468-474.

Desager, J. and A. Csinos 2005. Phytoxicity associated with drip applied 1,3-Dichlorpropene and chloropicrin in vegetables produced with plastic mulch. HortScience 40(3) 700-7006

Di Primo P., Gamliel A., Austerweil M., Bracha Steiner B., Peretz I., Katan J. (2003).Accelerated degradation of metham sodium and dazomet in soil: Characterization and consequences for pathogen control. Crop Protection 22:635-646.

Díez Rojo MA, López-Pérez JA, Urbano Terrón P, Bello Pérez A. (2011). *Biodesinfección de Suelos y Manejo Agronómico.* Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid, Spain, 414 pp. (http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/libro_de_biodesinfección_tcm7-156245.pdf)

Díez-Rojo, M.A., J. P López-Pérez, P. Urbano Terrón and A. Bello Pérez (2010).Biodesinfección de suelos y manejo agronómico. Ministry of the Environment, Government of Spain, Madrid, 408 pp.

Dong L., Huang C.D., Huang L., Li X.,.Zuo Y.,, (2012). Screening plants resistant against *Meloidogyne incognita* and integrated management of plant resources for nematode control. *Crop Protection*, *33 34-39*

Dwight S. (1999) .Reducing methyl bromide in preplant soil treatment for ginger root. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions.

EC Management Strategy. 2009. European Community Management Strategy for the Phase-out of the Critical Uses of Methyl Bromide, April 2009. Annex 4.C. http://ozone.unep.org/Exemption_Information/Critical_use_nominations_for_methyl_bromide/National_Management_Strategy_for_Phase.shtml

Elgorban A.M., Abdel-Wahab M.A., Bahkali A.H.,Al-sum, B.A. (2014). Biocontrol of *Meloidogyne javanica* on Tomato Plants by *Hypocrealixii* (the Teleomorph of *Trichoderma harzianum*).*CLEAN – Soil, Air, Water*. http://onlinelibrary.wiley.com/doi/10.1002/clen.201300430/abstract

Erin N. Rosskopf E.N. Kubota C.,Adkins S, Kokalis-Burelle N,, and. Hong J.C. (2013). Importance of Rootstock and Scion Tomato Mosaic Virus Resistance for Grafting Heirloom Tomatoes .Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2013, San Diego, California, .87

Evenhuis B., Nijhuis, E., Lamers J., Verhoeven J. and Postma J. (2014).Alternative methods to control *phytophthora cactorum* in strawberry cultivated in soilless growing media. Acta Hort. (ISHS) 1044:337-342

Fang X., Phillips D., Verheyen G., Li H., Sivasithamparam K., Barbetti M.J. (2012). Yields and resistance of strawberry cultivars to crown and root diseases in the field, and cultivar responses to pathogens under controlled environment conditions.*Phytopathologia Mediterranea*.51(1), 69-84

Fang X.L, Phillips D., Li H., Sivasithamparam K., Barbetti M.J. (2011a). Comparisons of virulence of pathogens associated with crown and root diseases of strawberry in Western Australia with special reference to the effect of temperature ScientiaHorticulturae 131, 39-48.

Fang X.L., Phillips D., Li H., Sivasithamparam K., Barbetti M.J. (2011b). Severity of crown and root diseases of strawberry and associated fungal and oomycete pathogens in Western Australia.Australasian Plant Pathology 40, 109-119.

Fennimore S.A., Serohijos R., Samtani J.B., Ajwa H.A., Subbarao K.V., Martin F.N., Daugovish O., Legard D., Browne G.T., Muramoto J., Shennan C., Klonsky K. (2013a). TIF film, substrates and nonfumigant soil disinfestation maintain fruit yields. California Agriculture 67, 139-146.

Fennimore S., Miller T. , Goodhue R., Dorn N., Broome J.,Muramoto J., Shennan C.and Martin F.(2013b). Evaluation of an automatic steam applicator in strawberry: 2012-13 resultsAnnual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2013, San Diego, California 11

Fennimore S., Samtani J., Subbarao K., (2011).Soil disinfestation in strawberry with steam. Proceeding of Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 46-1 – 46-3.

Fery R.L., Thies J.A. (2011a). Truhart-NR-, A root-knot nematode resistant, pimento-type pepper. .*HortScience*. 46(5), 815-816.

Fery R.L., Thies J.A. (2011b). PA-560, A Southern Root-knot Nematode Resistant, Yellow-fruited, Habanero-type Pepper. *HortScience*. 46(6), 946-947.

Foster J.M., Naegele R.P., (2013). Evaluation of Eggplant Rootstocks and Pepper Varieties for Potential Resistance to Isolates of *Phytophthora capsici* from Michigan and New York. Crop protection, 97, 8, 1037-1041

Fouillet T., Rebizak R., Descamps S., Ciesla Y., and Guery B.(2014).Development of a New Gastight Film Containing EVOH. In VIII International Symposium on Chemical and Non-Chemical Soil and Substrate Disinfestation 1044 (pp. 301-305).

Fritsch J., Fouillet T., Charles P., Fargier-Puech P., Ramponi-Bur C., Descamps S., Du Fretay G.,and Myrta A. (2014). French experiences with dimethyldisulfide (DMDS) as nematicide in vegetable crops. Acta Hort. 1044:427-433

Fujinaga M., Kobayashi H,, Komatsu K., Ogiso H., Uehara T., Ono Y., Tomita Y., Ogawara T. (2005). Control of fusarium yellows on celery by soil sterilization with hot water injection using a portable boiler *Annual Report of the Kanto Tosan Plant Protection Society.*No.52. 2005 Page 25-29.

Gamliel A., Triky S., Austerweil M., Peretz-Alon Y., Ucko, O. (2005). Combined soil fumigants: synergistic performance and improved yield. Acta Horticulturae 698, 135-140.

Gamliel A., Stapleton, J. J. (2012). Combining soil solarisation with organic amendments. Pages 109-120. In: Soil Solarisation-Theory and Practice (eds. Gamliel A. and Katan J) APS press, St. Paul MN USA.

Gamliel, A. 2014.application of soil disinfestation in the view of system approach: a bottleneck or a tool for improvement?. Acta Hort. (ISHS) 1044:245-2514.5 Crops specific strategies.

Gamliel A.,& Katan J. (Eds.). (2012). Soil solarisation theory and practice. St. Paul, MN, USA: APS Press, 266 pp.

García Ruíz A, Tello J.C, Avilés Guerrero M, Ordovás Ascaso J. (2009). *Fusariosis del Clavel. Fusarium oxysporum* f.sp. *dianthi. Últimos Avances en su Control*. Edit. Agrotécnicas, 275 pp.

García-Méndez E., García-Sinovas D., Becerril M., De Cal A., Melgarejo P., Martínez-Treceño A., FennimoreS. A., Soria C., Medina J.J.,López-Aranda J.M. (2009). Chemical alternatives to methyl bromide for weed control and runner plant production in strawberry nurseries. HortScience 43, 177-182.

Gay P.,Piccarolo P.,Ricauda A.D.,Tortia C., (2010).A high efficiency steam soil disinfestation system, part I:Physical background and steam supply optimization. Biosystems Engineering107, 74-85.

Gelsomino A., Petrovicová B., Zaffina F., Peruzzi A., (2010). Chemical and microbial properties in a greenhouse loamy soil after steam disinfestation alone or combined with CaO addition. Soil Biology and Biochemistry 42, 1091-1100.

Ghini R. (2014).Climate change and increasing challenges for effective soil disinfestation. Acta Horticulturae 1044: 447-454.

Ghini R.; Patrício F.R.A., Almeida I.M.G. (2007) Control of *Ralstonia solanacearum* in tomato potting medium by the use of a solar collector. Australasian Plant Disease Notes 2, 77-78.

Gilardi G., Demarchi S., Martano G., Gullino M.L. and Garibaldi A. (2014a).Success and failures of grafting pepper against soil-borne pathogens. Acta Hort. (ISHS) 1044:67-71

Gilardi G., Gullino M.L.,Garibaldi A., Ricauda Aimonino D. and Luongo I. (2014b). Different steaming methods to control Fusarium wilt agents under simulated conditions. Acta Hort. (ISHS) 1044:237-242

Gilardi, G., Demarchi, S., Moizio, M., Gullino, M.L. and Garibaldi, A. (2014c). Disease management strategies against fusarium wilt of basil and rocket by combining amendments and soil solarisation. Acta Hort. (ISHS) 1044:319-324

Gilardi, G., Pugliese, M., Colla, P., Gullino, M.L. and Garibaldi, A. (2014d). Management of *Phytophthora capsici* on bell pepper and C*olletotrichum coccodes* on tomato by using grafting and organicamendments . Acta Hort. (ISHS) 1044:257-262

Gilardi G., M. Baudino, M. Moizio, M. Pugliese, A. Garibaldi, M.L. Gullino, (2013a).Integrated management of *Phytophthora capsici* on bell pepper by combining grafting and compost treatment.*Crop Protection*, *53*, *13-19*

Gilardi G., Gullino M. L.,Garibaldi A. (2013b). Critical aspects of grafting as a possible strategy to manage soil-borne pathogens.*Scientia Horticulturae*149,19-21.

Gisbert C., Prohens J., Nuez F. (2011a).Performance of eggplant grafted onto cultivated, wild, and hybrid materials of eggplant and tomato. *International Journal of Plant Production* 5(4), 367-380.

Gisbert C., Prohens J., Raigón M.D., Stommel J.R., Nuez F. (2011b). Eggplant relatives as sources of variation for developing new rootstocks: Effects of grafting on eggplant yield and fruit apparent quality and composition.*Scientia Horticulturae* 128, 14–22.

Gong B., Bloszies S., Li X., Wei M., Yang F. J., Shi Q. H. and Wang X.F., (2013). Efficacy of garlic straw application against root-knot nematodes on tomato. In: Scientia Horticulturae, 161, 49-57.

González J.C., González Ruiz J, Domínguez M, Afonso R, Domínguez E, Domínguez K, Hernández M, López Cepero J, Piedra Buena A, López Pérez JA, Arias Mª, Tello JC, Bello A. (2013). Diversidad y complementaridad en la gestión agroecológica. *XXI Jornadas Técnicas Estatales SEAE: Desarrollo Rural, Innovación Agroecológica y Agricultura Ecológica en la PAC.* Alcalá de Henares, Madrid, 26-27 septiembre, 39 pp. https://docs.google.com/file/d/0B-jLDCjL-kpxWFQ5NDVuNzRmbDg/edit.

González Ruiz J, Domínguez M, Afonso R, Domínguez E, Domínguez K, Hernández M, González JC, Ballester J, Gallego A, López Cepero J, Piedra Buena A, López Pérez JA, Torres Nieto JM, García Ruiz A, Arias M, Lacasa A, Tello JC, Gonzálvez V, Bello A. (2014). Agricultura familiar, investigación agroecológica participativa y formación. *Simposium Agricultura Familiar Agroecológica*, SEAE. Lugo, 18 - 20 Junio, 15 pp.

Gordon T.R., Koike S.T., Daugovish O., Shaw D.V., Larson K.D. (2011). A Comprehensive Approach to Management of Wild Diseases Caused by *Fusarium oxysporum* and *Verticillium dahliae*. California Strawberry Commission Annual Production Research Report, 2010-2011.

GTHB, (2014). The Ministry of Food, Agriculture and Livestock, The General Directorate of Crops Porduction, Annual Statistical Report, November, 2014.http://www.tarim.gov.tr/sgb/Belgeler/SagMenuVeriler/BUGEM.pdf

Guan W., Zhao, X., Hassell, R. Thies, J. (2012). Defense mechanisms involved in disease resistance of grafted vegetables. *HortScience* ,. 47, 2 164-170

Guerrero –Diaz M. M., Ros C., Lacasa C. M., Martinez V., Lacasa A., Fernandez P., Martinez M. A., Nunez-Zofio M., Larregla S., Diez-Rojo M. A., Bello A. (2010). Effect of biosolarisation using pellets of *Brassica carinata* on soil-borne pathogens in protected pepper crops. *Acta Horticulturae* 883, 337-344.

Guerrero-Díaz M.M., Lacasa-Martinez C.M., Hernández A., Martínez V., Martínez M.C., Fernández-Molina, P. and Lacasa A. (2014). Biosolarisation with agro-industrial by product for the control of soilborne pathogens in protected pepper crops in southeast spain. Acta Hort. (ISHS) 1044:157-161

Gullino M.L., Minuto A., Gilardi G., Garibaldi A., Ajwa H., Duafala T. (2002). Efficacy of preplant soil fumigation with chloropicrin for tomato production in Italy. Crop Protection 21: 741-749

Gyoutoku Y., Eguchi T., Moriyama M.,KashioT.,Yokoyama T. (2007). Integrated pest management on autumn-winter muskmelon by using physical and biological control agents. *Research Bulletin of the Kumamoto Prefectural Agricultural Research Center* ,.14,111 -127

Hansen, Z. R. Keinath, A. P. ,(2013). Increased pepper yields following incorporation of biofumigation cover crops and the effects on soilborne pathogen populations and pepper diseases. Applied Soil Ecology;.63:67-77.

Hanson, B.D., Gerik J.S , and Schneider S.M . (2010). Effects of reduced-rate methyl bromide applications under conventional and virtually impermeable plastic film in perennial crop field nurseries. *Pest Management Science*: 66:892-899.

Heller J.J., Korkmaz E.,and Charles P.,(2010). Evaluation of the efficacy of DMDS using drip application for the control of root-knot nematodes (*Meloidogyne* spp.) in Turkey.Acta Hort. 883: 171-174.

Heller J.J., Sunder P., Charles P., Pommier J.J., Fritsch, J. (2009).Dimethyl disulfide, a new alternative to existing fumigants on strawberries in France and Italy. Acta Horticulturae, 842, 953-956.

Hepperly P;, Zee F, Kai R., Arakawa C., Meisner M., Bernard ,Kratky M., ,Hamamoto K., and Sato D.., (2004). Producing Bacterial Wilt–Free Ginger in Greenhouse Culture. Soil and Crop Management. SCM-8 , June 2004.

Hermosa R., Rubio M.B., Cardoza R.E., Nicolás C., Monte E., and Gutiérrez S., (2013). The contribution of *Trichoderma* to balancing the costs of plant growth and defense. In: International Microbiology, 16(2), 69-80.

Hong J., Rosskoph E., Martin K., Kokalis-Burelle N. Butler D. (2012).Insight onto anaerobic soil disinfestation through the lens of molecular biology. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, Maitland, Florida USA.

Huang Y., Li J., Hua B., Liu Z., Fan M., Bie Z. (2013). Grafting onto different rootstocks as a means to improve watermelon tolerance to low potassium stress.*ScientiaHorticulturae,* 149, 86–96

Jari S., Michael M., Archana P., Ted R., Steve F., Susan M. (2011). Evaluations of tomato yellow leaf curl virus resistant varieties for commercial production. *The Food Provider.*June- July-August 2011, pp.1-6.

Jayesh B. S., A. Ajwa H.A., Weber J.B., Browne G.T., Susanne Klose, Jonathan Hunzie, Steven A. Fennimore, (2011). Evaluation of non-fumigant alternatives to methyl bromide for weed control and crop yield in California strawberries (*Fragaria ananassa* L.). Crop Protection, Volume 30, Issue 1, January 2011, Pages 45-51

Ji P., Kone D., Jackson K.L., Csinos A.S. (2012). Soil amendments with Brassica cover crops for management of Phytophthora blight on squash. *Pest Management Science*. 68, 639-644

Ji X., Qiao K., Dong S., Wang H., Xia X., Wang K. (2013). Effects of 1, 3-dichloropropene plus chloropicrin on weed seed germination. Crop Protection 45, 1-5.

Kaewchai S., Soytong K., and Hyde K. D., (2009).Mycofungicides and fungal biofertilizers. In: Fungal diversity, 38, 25-50.

Karaca F., Yetişir H., Solmaz İ.,Çandır E., Kurt Ş., Sarı N., Güler Z. (2012). Rootstock potential of Turkish *Lagenaria siceraria* germplasm for watermelon: plant growth, yield, and quality. *Turkish J Agriculture and Forestry* 36, 1101-1716

Katan J. (2014a).*Soil solarisation: the idea, the research and its development*; Phytoparasitica; June 2014; Springer Netherlands

Katan, J. (2014b). Integrated pest management in connection with soil disinfestation. Acta Hort. 1044:19-28

Katan J., Gamliel A. (2012a). Soil solarisation for the management of soilborne pests: the challenge, historical perspective and principles. Pages 45-52. In: Soil Solarisation-Theory and Practice (eds. Gamliel A. and Katan J) APS press, St. Paul MN USA

Katan, J.and Gamliel, A. (2012b). Mechanisms of pathogen and disease control and plant growth improvement involved in soil solarisation. In A. Gamliel & J. Katan (Eds.), *Soil solarisation: theory and practice* (pp. 135–145). St. Paul, MN, USA: APS Press.

KatanJ., and Gamliel A. (2012c). *Soil solarisation: theory and practice* . St. Paul, MN, USA: APS Press, 266 pp.

Katan J., Greenberger A., Alon H., & Grinstein, A. (1976).Solar heating by polyethylene mulching for the control of diseases caused by soil-borne pathogens. Phytopathology, 66, 683– 689.

KatanJ.,& Gamliel A. (2010). Soil solarisation - 30 years on: What lessons have been learned? In U. Gisi, I. Chet, & M. L. Gullino (Eds.),*Recent developments in management of plant diseases* (pp. 265–284). Dordrecht, the Netherlands: Springer.

Keinath A.P**.,-**Hassell R. L. (2014). Control of Fusarium Wilt of Watermelon by Grafting onto Bottle gourd or Interspecific Hybrid Squash Despite Colonization of Rootstocks by *Fusarium.* Plant Diseases, 98,255-266.

Keinath A.P.and Hassell R.L. (2013).Evaluation of grafting to control race 2 of Fusarium wilt on watermelon .Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2013, San Diego, California, 88

King S. R., Davis, A. R., Liu, W., and Levi, A. (2008). Grafting for disease resistance. *Hortscience* 43, 1673-1676.

Klein E., Katan J., Gamliel A. (2011).Soil suppressiveness to Fusarium disease following organic amendments and solarisation; Plant Disease, 95 (2011), pp. 1116–1123

Klein E., Katan J., .Gamliel A., 2012. Soil suppressiveness to *Meloidogyne javanica* as induced by organic amendments and solarisation in greenhouse crops. *Crop Protection*, *Volume 39*, *26-32.*

Kobara Y, Momma N. and Yogo Y. (2012).Biological soil disinfestation (BSD) techniques with diluted ethanol. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, Maitland, Florida USA.

Kobara Y. Momma N. and Yogo Y. (2011).Biostimulated redox processes in soils disinfested with ethanol solution. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, San Diego, California USA.

Koike S.T. (2008). Crown rot of strawberry caused by *Macrophomina phaseolina* in California. Plant Disease 92, 1253.

Koike S.T., Ajwa H.,Daugovish O., Bolda M., (2009). Fumigant and strawberry variety evaluations in M*acrophomina* and *Fusarium* fields ,http://mbao.org/2009/Proceedings/013DaugovishO.SummaryPathogens.pdf

Koike S.T., Daugovish O., Gordon T., Ajwa H., Othman M., Subbarao K., Bolda M., Legard, D.(2011). Biology and Management of Macrophomina Disease of Strawberry in California.California Strawberry Commission Annual Production Research Report, 2010-2011.

Koike S.T., Gordon, T.R., Daugovish, O., Ajwa, H., Bolda, M., Subbarao, K. (2013).Recent Developments on strawberry plant collapse problems in California caused by *Fusarium* and *Macrophomina .International Journal of Fruit Science* 13 (1-2) , pp. 76-83

Koike S.T., Kirkpatrick S.C., Gordon, T.R. (2009). Fusarium wilt of strawberry caused by *Fusarium oxysporum* in California.Plant Disease 93, 1077.

Koike, S. T.Gordon, T. R. Daugovish, O. Ajwa, H. Bolda, M. Subbarao, K. , (2013). Recent developments on strawberry plant collapse problems in California caused by *Fusarium* and *Macrophomina.* International Journal of Fruit Science; ,13 (1/2):76-83.

Kokalis-Burelle N., Butler D.M. and Rosskopf E.N.(2013) . Effects of cover crops with potential for use in anaerobic soil disinfestation (ASD) on reproduction of M*eloidogyne* spp. Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2013, San Diego, California, 65

Koron D., Sonjak S., Regvar M., (2014). Effects of non-chemical soil fumigant treatments on root colonisation with arbuscular mycorrhizal fungi and strawberry fruit production. Crop Protection, Volume 55, January 2014, Pages 35-41

Korthals G.W., Thoden T. C., van den Berg W., and Visser J.H.M., (2014).Long-term effects of eight soil health treatments to control plant-parasitic nematodes and *Verticillium dahliae* in agro-ecosystems.Applied Soil Ecology, 76, 112-123.

Kousik C. S., Thies J. A., Donahoo R., Hassell R. (2010). Grafting Seedless Watermelons, How and Why? Will Grafting Help With Disease Control?.*Atlantic Coast Agriculture Conference and Trade Show.* pp 38-39

Kousik C.S, Donahoo R.S, Hassell R., (2012). Resistance in watermelon rootstocks to crown rot caused by *Phytophthora capsici.Crop Protection*, *39*, *18-25*

Lambrix V., Reichelt M., Mitchell-Olds T., Kliebenstein D.J., Gershenzon, J. (2001). The *Arabidopsis* epithiospecifier protein promotes the hydrolysis of glucosinolates to nitriles and influences Trichoplusia ni herbivory. Plant Cell, 13, 2793-2807.

Lee N.M., Kim H. J., Kim K. D., Yoo D. L. And Suh J. T. (2012).Characteristics of new ever-bearing strawberry “Gwanha” cultivar for ornamental horticulture. *Korean Journal of Horticultural Sciences and Technology* 30(6): 784-787

Leocata S., Pirruccio G., Medico E., Myrta A.,and Greco N.(2014). Dimethyl disulfide (DMDS): a new fumigant to control root-knot nematodes *Meloidogyne* spp. In protected crops in Sicily, Italy. Acta Hort. 1044:415-420

Li Y., Chi L., Mao L., Yan D., Wu Z., Ma T., Guo M., Wang Q., Ouyang C., and, Cao A.(2014a) Control of Soil-borne Pathogens of *Zingiber officinale* by Methyl Iodide and Chloropicrin in China. Plant Disease, , 384-388

Li Y., Mao L., Yan D., Ma T., Shen J., Guo M., Wang Q., Ouyang C., Cao A. (2014b).Quantification of *Fusarium oxysporum* in fumigated soils by a newly developed real-time PCR assay to assess the efficacy of fumigants for Fusarium wilt disease in strawberry plants, Pest Management Science, (wiley online library.com) DOI 10.1002/ps.3700.

Liu B, Ren J, Zhang Y, An J, Chen H, Xu C, Ren H. (2014). A new grafted rootstock against root-knot nematode for cucumber, melon, and watermelon. *Agronomy for Sustainable Development*.DOI 10.1007/s13593-014-0234-5

Lodha, S., Mawar, R. and Saxena, A. (2014).Compost application for suppression of M*acrophomina phaseolina* causing charcoal rot in arid crops. Acta Hort. (ISHS) 1044:307-312

Lombardo S., Lango A.M.G., Lo Monaco A., Mauromicale G., (2012).The effect of soil solarisation and fumigation on pests and yields in greenhouse tomatoes *. Crop Protection*, *37*, *59-64*

Longo A., Feratto J., Mondino M., Grasso R. (2013). Efecto de diferentes tratamientos de suelos sobre la productividad y calidad de los cultivos de lechuga y tomate en invernadero; Revista FAVE - Ciencias Agrarias 1 (1): 101 - 105. 2002, Argentina.

López Pérez J.A., Roubtsova T, García M de Cara, Ploeg A. (2010). The potential of five winter-grown crops to reduce root-knot nematode damage and increase yield of tomato.*J. Nematol.*42, 120-127.

López-Aranda J.M., Miranda L., Medina J.J., Soria C., Santos B.D.L., Romero F., Pérez-Jiménez R.M.,Talavera M., Fennimore S.A., Santos B.M. (2009a). Methyl bromide alternatives for high tunnel strawberry production in southern Spain.HortTechnology, 19, 187-192.

López-Aranda J.M., Miranda L., Soria C., Pérez-Jiméne, R.M., Zea T., Talavera M., Romero F., De LosSantos B., Vega J.M., Páez J.I., Bascón J., Domínguez F.J., Palencia P., Medina, J.J. (2009b). Chemical alternatives to methyl bromide for strawberry in the area of Huelva (Spain): 2002-2007 results. Acta Horticulturae 842, 957-960.

Lopez-Aranda, J 2012. Methyl Bromide Alternatives (Chemical and Nonchemical) for Strawberry Cultivation in Conventional Areas of Production. Proceedings of the VII International Strawberry Symposium 2012, Beijing, China.*ActaHorticulturae*

López-Elías J., Guerrero-Ruíz J., Huez-López M., Jiménez-León J., Ruiz-Mendoza J. (2014). Biofumigación y solarización del suelo en la producción de sandía (*Citrullus lanatus* (Thunb.) Matsum.&Nakai); European Scientific Journal, January 2014 edition vol.10, No.3 ISSN: 1857 – 7881

Louws F J, Rivard C L, Kubota C. (2010).Grafting fruiting vegetables to manage soilborne pathogens, foliar pathogens, arthropods and weeds*. Scientia Horticulturae* 127, 127–146.

Mancini V., and Romanazzi G., (2014).Seed treatments to control seed-borne fungal pathogens of vegetable crops. Pest management science, 70(6), 860-868.

Mao L., Wang Q., Yan D., Xie H., Li Y., Guo M., Cao, A. (2012). Evaluation of the combination of 1,3-dichloropropene and dazomet as an efficient alternative to methyl bromide for cucumber production in China. *Pest Manage. Sci*. 68, 602-609.

Mao L., Yan D., Wang Q., Li Y., Ouyang C., Liu P., Shen J., Guo M., Cao A., (2014a). Evaluation of the Combination of Dimethyl Disulfide and Dazomet as an Efficient Methyl Bromide Alternative for Cucumber Production in China. *J. Agric. Food Chem*. 62, 4864-4869.

Mao L.., Wang Q.., Yan.D., Ma T., Liu P., Shen J., Li Y., Ouyang C., Guo M., Cao A.. (2014b). Evaluation of chloropicrin as a soil fumigant against *Ralstonia solanacarum* in ginger (*Zingiberofficinale*Rosc.) production in China. PloS one, 9(3), e91767.

Marshall M., Rumsey T., Stapleton J.,(Vandergheynst J.S. (2013). A predictive model for soil temperature during solarisation and model validation at two California field sites; Transactions of the ASABE 2013, American Society of Agricultural Engineers; vol. 56, no1, pp. 117-133 [17 page(s) (article)] (1 p.1/4).

Marsic N.K., Jakse M., (2010).Growth and yield of grafted cucumber (*Cucumis sativus* L.) on different soilless substrates. Journal of Food Agriculture & Environment 8, 654-658.

Martin C.G., Eudoxie G.D., Black K. C., Brathwaite R.A. I., Lauckner B. (2014). Assessing maturity of rotary barrel green waste composts for use as tomato and sweet pepper seedling starter and transplant growth substrates.*International Journal of Vegetable Science* 20, 28-58

Martínez B., Figueroa A., Baday E., and Mejia P.,(2010) Uso de aislamientos de *Trichoderma* para el control de enfermedades en melon en Choluteca. Fitosanidad 14(1):55

Martinez M. A., Martinez M.C., Bielza P., Tello J.,Lacasa A. (2011). Effect of biofumigation with manure amendments and repeated biosolarisation on Fusarium densities in pepper crops.*Journal of Industrial Microbiology and Biotechnology* 38(1), 3-11

Martínez M.A., Martínez M.C., Bielza P, Tello J, Lacasa A. (2009). Effect of biofumigation with manure amendments and repeated biosolarisation on *Fusarium* densities in pepper crops.*J. Ind. Microbiol. Biot.*38, 3-11.

Mashela P., Pofu K., Nzanza B. (2013.) Suitability of *Brassica oleracea* leaves in managing *Meloidogyne incognita* through the ground leaching technology system under microplot conditions. *Acta Agriculturae Scandinavica,* Section B - Soil & Plant Science; 63(1), 19-24.

Mattner, S.W., Milinkovic, M., Merriman, P.R. and Porter, I.J. (2014).Critical challenges for the phase-out of methyl bromide in the Australian strawberry industry. Acta Hort. (ISHS) 1044:367-373

Mattner, S.W., Porter, I.J., Gounder, R.K., Mann, R.C., Guijarro, B. and Williams, E.N. (2010).Maintaining biosecurity and market access in the Australian strawberry industry following methyl bromide phase-out. *Acta Horticulturae* (ISHS) 883: 99-106.

Mawar, R. and Lodha, S. (2014). Combining sub-lethal heating and cruciferous amendments for improved control of M*acrophomina phaseolina*. Acta Hort. (ISHS) 1044:289-293

McAvoy, T. Freeman, J. H. (2013). Yellow nutsedge (*Cyperus esculentus*) control with reduced rates of dimethyl disulfide in combination with totally impermeable film. Weed Technology; 27(3):515-519.

McKenry, M. (2011). Fifty years with a nematode-free nursery program. . In: Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, California USA. http://www.mbao.org/2011/Proceedings/11McKenryM.pdf

Melero-Vara J. M., Lopez-Herrera C. J., Prados-Ligero A. M., Vela-Delgado M. D., Navas-Becerra J. A., Basallote-Ureba, M. J. (2011). Effects of soil amendment with poultry manure on carnation Fusarium wilt in greenhouses in southwest Spain.*Crop Protection*..30(8), 970-976.

Melero-Vara J. M., Vela-Delgado M., Basallote-Ureba, M., López Herrera C., Pelegrín, F., Talavera M. (2012a). Control de las agallas radiculares del clavel mediante enmiendas orgánicas al suelo, seguidas de solarización; XVI Congreso de la Sociedad Española de Fitopatología; Sociedad Española de Fitopatología

Melero-Vara J.M., C. J. López-Herrera, M. J. Basallote- A. M. Prados, M. D. Vela ,F. J. Macias, E. Flor-Peregrín and M. Talavera, (2012b). Use of Poultry Manure Combined with Soil Solarisation as a Control Method for *Meloidogyne incognita* in Carnation. Plant Dis. 96, 7, 990-996

Mennan S., Melakeberhan H. (2010). Effects of biosolid amendment on populations of *Meloidogyne hapla* and soils with different textures and pHs. *Bioresource Technology* 101(18), 7158-7164.

Meyer M. D.and Hausbeck M.K, (2013).Using Soil-Applied Fungicides to Manage Phytophthora Crown and Root Rot on Summer Squash. Plant Dis. 97, 107-112

Michel M., (2009). Implementación de un programa de eliminación de bromuro de metilo en la empresa Excosur. UNIDO Investment project on MB alternatives for melons.

Michel V.V., Lazzeri L. (2010). Green manures and organic amendments to control corky root of tomato.*Acta Hort*. (ISHS) 883, 287-294

Miles C A, Keider P, Hasenhoerly K, Inglis D A. (2013a).Plant Growth, Fruit Yield and Quality, and Tolerance to Verticillium Wilt of Grafted Watermelon and Tomato in Field Production in the Pacific Northwest.*HortScience* 48:1003-1009

Miles C.A, Hesnault L., Johnson S., Kreider P. (2013b). Vegetable grafting: Watermelons. Washington State University Extension Fact Sheet FS100E.htpp://pubs.wsu.edu

Minuto A., GullinoM.L., Lamberti F., D'AddabboT., Tescari E., Ajwa H., Garibaldi A.. (2006). Application of an emulsifiable mixture of 1,3-dichloropropene and chloropicrin against root knot nematodes and soilborne fungi for greenhouse tomatoes in Italy.Crop Protection 25: 1244–1252.

Misawa T., Sinmura A. (2010) Control effectiveness of biological soil disinfestation and some fungicides against Phytophthora rot strawberry caused by phytophthora cactorum and its duration. Ann.Rept.PlantProt. North Japan 61: 80-84 (2010)

MLF (2012) Evaluation of Methyl Bromide projects in Africa – Desk study. UNEP/OzL.Pro/ExCom/66/15. March, 2012. http://www.multilateralfund.org/66/English/1/6615.pdf

Mohamed F., El-Hamed K., Elwan M., Hussien M-A. (2012). Impact of Grafting on Watermelon Growth, Fruit Yield and Quality.*Vegetable Crops Research Bulletin.* 76, 99–118

Mokbel A., Saedy M. (2013). The Potential of Soil Solarisation and Chemical Nematicides in Controlling *Meloidogyne incognita* Infected Grapevine Seedlings; Journal of Life Sciences and Technologies; Vol. 1, No. 1, March 2013.

Mollinedo V. (2013). La solarización: una realidad en la producción hortícola del NOA. Editoras, Mitidieri, M. y Francescangeli N, Serie capacitaciones. no. 5., 1a. ed.; Ediciones INTA. San Pedro. Argentina; p. 42-44.

Momma N., Kobara Y., Uematsu S., Kita N., Shinmura A.,(2013). Development of biological soil disinfestation in Japan. Appl Microbiol Biotechnol DOI 10. 1007/s00253-013-4826-9 Springer-Verlag Berlin Heiderberg 2013 Published online: 03 April 2013

Momma N., Momma M., Kobara Y. (2010).Biological soil disinfestation using ethanol: effect on *Fusarium oxysporum* f.sp.*lycopersici* and soil microorganisms. Journal of General Plant Pathology 76(5): 336-344

Monge-Pérez J. (2013). Producción y exportación de melón (Cucumis melo) en Costa Rica; Revista Tecnología en Marcha; Vol. 27, Nº 1. Pág.93-103. Available at http://www.tec-digital.itcr.ac.cr/servicios/ojs/index.php/tec_marcha/article/viewFile/1700/1562

Morales-Rodríguez C., Palo C.,.Palo E., and.Rodríguez-Molina M.C. , 2014 Control of *Phytophthora nicotianae* with Mefenoxam, Fresh *Brassica* Tissues, and *Brassica* Pellets.Crop protection, 98,77-83

Morales-Rodriguez C., Picon-Toro J., Palo C., Palo E. J., Garcia A., and Rodriguez-Molina C., (2012). In vitro inhibition of mycelial growth of *Phytophthora nicotianae* Breda de Haan from different hosts by Brassicaceae species.Effect of the developmental stage of the biofumigant plants.Pest Management Science, 68, 1317-1322.

Morita Y. (2012) Construction of a Cultivation Manual for Ginger in Open Fields without Methyl Bromide in Kochi Prefecture; Plant Protection 2012 Vol.66 No.12 Page 24-28

Morra L., Bilotto M., Carrieri R., Lahoz E. (2013). Graft and solarisation in controlling *Phytophihora capsici* on bell peppers.*Colture Protette*; 42(1), 64-70.

Mowlick S., Yasukawa H., Inoue T., Takehara T., Kaku N., Ueki K., and Ueki A., (2013). Suppression of spinach wilt disease by biological soil disinfestation incorporated with *Brassica juncea* plants in association with changes in soil bacterial communities. Crop Protection, 54, 185-193.

Muñoz Villalobos J., Macías Corral M., Macías Rodríguez H., Velásquez Valle M., Tapia Vargas L. (2013). Bio-fumigation as Alternative for the Control and Prevention of Pathogens in the Soil in the Pepper Crop (*Capsicum annuum* L.) in the Valley of Nazas, Durango; Revista Agrofaz; volumen 13; número 2; 201; México. Available at http://www.agrofaz.mx/wp-content/uploads/articulos/2013132III_2.pdf

Muramoto, J., Shennan, C., Baird, G., Zavatta, M., Koike, S.T., Bolda, M.P., Daugovish, O., Dara, S.K., Klonsky, K. and Mazzola, M.(2014) .Optimizing anaerobic soil disinfestation for California strawberries. Acta Hort. (ISHS) 1044:215-220

Noling, J (2014). Large Scale Field Demonstration Trialing of Fumigant Alternatives in Florida Strawberry 2013-2014, MBAO, Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2014, Orlando, Florida

Noling, J and Cody M. (2013). Large Scale Field Demonstration Trialing of Fumigant Alternatives in Florida Strawberry 2012-2013, MBAO, Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2013, San Diego, California, 23

Nuñez-Zofio M, Larregla S, Garbisu C. (2011). Application of organic amendments followed by soil plastic mulching reduces the incidence of *Phytophthora capsici* in pepper crops under temperate climate. *Crop Prot.* 30, 1563-1572.

Nuñez-Zofio M, Larregla S, Garbisu C, Guerrero MM, Lacasa CM, Lacasa A. (2013). Application of sugar beet vinasse followed by solarisation reduces the incidence of *Meloidogyne incognita* in pepper crops while improving soil quality. *Phytoparasitica* 41, 2, 181-191.

Nuñez-Zofio M, Larregla S, Garbisu C. (2012). Repeated biodisinfection controls the incidence of *Phytophthora* root and crown rot of pepper while improving soil quality. *Spanish J. Agricultural Research* 10, 794-805.

Nyczepir, A.P., Kluepfel, D.A., Waldrop, V. & Wechter, W.P. (2012) Soil Solarisation and Biological Control for Managing *Mesocriconema xenoplax* and Short Life in a Newly Established Peach Orchard. *Plant Disease*, **96**, 1309-1314.

Ogai R., Kanda-Hojo A., Tsuda S. (2013). An attenuated isolate of Pepper mild mottle virus for cross protection of cultivated green pepper (*Capsicum annuum* L.) carrying the L3 resistance gene. *Crop Protection* 54; 29-34

Oka Y., (2010).Mechanisms of nematode suppression by organic soil amendments-A review. Applied Soil Ecology, 44, 101-115.

Oka Y., Shuker S., Tkachi N., Trabelcy B., and Gerchman Y., (2014).Nematicidal activity of *Ochradenus baccatus* against the root-knot nematode *Meloidogyne javanica*. Plant Pathology, 63, 221-231.

Okon Levy N., Meller Harel Y., Haile Z.M., Elad Y., Rav-David E., Jurkevitch E. and Katan J. (2014).Induced resistance to foliar diseases by soil solarisation and *Trichoderma harzianum*. Plant Pathology.doi: 10.1111/ppa.12255

Oumouuloud A., El-Otmani M., Chikh-Rouhou H., Claver A. G.,Torres R. G., Perl-Treves R.Álvarez, J. M. (2013). Breeding melon for resistance to Fusarium wilt: recent developments. *Euphytica* 192, 155-169.

Oyamada K., Suzuki S. ,Wada E., Saito Y. (2003). Control of Fusarium Wilt (*Fusarium oxysporum* f.sp. *fragariae*) on strawberry by soil reduction.Annual Report of the Kanto-Tosan Plant Protection Society. No.50

Özalp, R. and Aktaş, A., (2008).Türkiye ve Antalya'da sebzeciliğin genel durumu.*Tarımın Sesi Dergisi,* 17:15-18. Antalya.

Ozores-Hampton M., McSorley R., and Stansly P.A., (2012).Effects of long-term organic amendments and soil sanitation on weed and nematode populations in pepper and watermelon crops in Florida. In: Crop Protection, 41, 106-112.

Öztekin G.B., Tuzel Y. (2011). Salinity response of some tomato rootstocks at seedling stage.*African Journal of Agricultural Research* 6(20), 4726-4735

Ozturk, A.; Yilmaz, S.; Kececi, M.; Unlu, A.; Deviren, A.; Ozcelik, A.; Cetinkaya, S.; Cevri, H.; Akkaya, F. and Ozkan, C.F. (2002). Alternatives to methyl bromide for tomato and cucumber production in Turkey.*Proceeding of Alternatives to Methyl Bromide*. Sevilla, Spain. pp. 194-199.

Paes J.L., Faroni L.R.D.A., Dhingra O.D., Cecon P.R., Silva, T.A. (2012). Insecticidal fumigant action of mustard essential oil against *Sitophilus zeamais* in maize grains. Crop Protection, 34, 56-58.

Pérez-Jiménez R. M., De Cal A., Melgarejo P., Cubero J., Soria C., Zea-Bonilla T. Larena I. (2012). Resistance of several strawberry cultivars against three different pathogens.*Spanish Journal of Agricultural Research* 10(2), 502-512

Phillips A.J.L.,(1990) The effects of soil solarisation on sclerotial populations of *Scerotinia sclerotiorum*. Plant Pathol. 39:38-43

Piedra Buena A, García-Alvarez A, Díez-Rojo MA, Ros C, Fernández P, Lacasa A, Bello A. (2007). Use of pepper crop residues for the control of root-knot nematodes.*BioresourTechnol*. 98, 2846-2851.

Porter, I.J., Pizano M;,and Besri M;, 2007. Impact of the Montreal Protocol regulations on preplant soil use and trends in adoption of alternatives. In: Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, California ,USA. http://www.mbao.org/2007/Proceedings/065PorterI2007Final.pdf

Porter, I.J., Trinder L., Partington, D.C (2006). Special report validating the yield performance of alternatives to methyl bromide for preplant fumigation.TEAP/MBTOC Special Report, UNEP Nairobi, May 2006, 97 pp.

Postma, J., Schilder, M.T. and Stevens, L.H. (2014).The potential of organic amendments to enhance soil suppressiveness against R*hizoctonia solani* disease in different soils and crops. Acta Hort. (ISHS) 1044:127-132

Pugliese M., Gullino M. L., Garibaldi A., Marenco, M. (2014a). Control of soilborne pathogens on vegetables grown in greenhouse by microorganisms isolated from compost. *Acta Horticulturae* 1044, 253-256.

Pugliese, M., Gullino, M.L., Garibaldi , A. and Benetti, A. (2014b). Use of compost from different origins to control soilborne pathogens in potted vegetables. Acta Hort. (ISHS) 1044:145-148

Putter I (1981) New insecticides and acaricides and nematiicide-avermectins. Experientia 37:963-964.

Qiao K., Liu X., Wang H., Xia X., Ji X. Wang K. (2012a). In: Effect of abamectin on root-knot nematodes and tomato yield. Pest Management Science , 68, 853–857.

Qiao K., Dong S., Wang H., Xia X., Ji X., Wang K. (2012b).Effectiveness of 1,3-dichloropropene as an alternative to methyl bromide in rotations of tomato (*Solanum lycopersicum*) and cucumber (*Cucumis sativus*) in China. Crop Protection38, 30-34.

Qiao K., Zhu Y., Wang H., Ji X., & Wang K. (2012c).Effects of 1, 3-dichloropropene as a methyl bromide alternative for management of nematode, soil-borne disease, and weed in ginger (*Zingiber officinale*) crops in China. Crop Protection, 32, 71-75.

Qiao K., Shi X., Wang H., Ji X., Wang K. (2011). Managing root-knot nematodes and weeds with 1,3-dichloropropene as an alternative to methyl bromide in cucumber crops in China. Journal of Agricultural and Food Chemistry, 59, 2362-2367.

Qiao K., Jiang L., Wang H., Ji X., Wang K., (2010a). Evaluation of 1,3-dichloropropene as a methyl bromide alternative in tomato crops in China. Journal of Agricultural and Food Chemistry, 58, 11395-11399.

Qiao K., Wang H.Y., Shi X.B., Ji X. X., Wang K.Y. (2010b). Effects of 1,3-dichloropropene on nematode, weed seed viability and soil-borne pathogen. Crop Protection, 29, 1305-1310.

Reyes A.,(2013) Personal communication. UNIDO project, Honduras

Ricárdez-Salinas M..Huitrón-Ramírez M. V., Tello-Marquina J. C., Camacho-Ferre F. (2010). Planting density for grafted melon as an alternative to methyl bromide use in Mexico. *ScientiaHorticulturae,* 126(2), 236-24

Rosskopf E., Kokolis-Burelle N., Butler D., MuramotoJ., Shennan C. (2010). Development of anaerobic soil disinfestation for Florida vegetable and flower production.Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, Orlando Florida USA.

Rosskopf, E.N., Burelle, N., Hong, J., Butler, D.M., Noling, J.W., He, Z., Booker, B. and Sances, F. (2014).Comparison of anaerobic soil disinfestation and drip-applied organic acids for raised-bed specialty crop production in Florida. Acta Hort. (ISHS) 1044:221-228

Rosskopf E., Kokalis-Burelle N., Hong J., Butler D. (2012).Status of ASD development in Florida. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, Maitland, Florida USA.

Roux-Michollet D., Dudal Y., Jocteur-Monrozier L., Czarnes S., (2010). Steam treatment of surface soil: How does it affect water-soluble organic matter, C mineralization, and bacterial community composition? Biology and Fertility of Soils 46,607-616.

Saglam O., Ozder N. (2013). Fumigant toxicity of monoterpenoid compounds against the confused flour beetle, *Tribolium confusum* Jacquelin du Val. (Coleoptera: Tenebrionidae). Turkiye Entomoloji Dergisi-Turkish Journal of Entomology, 37, 457-466.

Samtani J.B., Gilbert C., Ben Weber J., Subbarao K.V., Goodhue R.E., Fennimore S.A., (2012). Effect of steam and solarisation treatments on pest control, strawberry yield, and economic returns relative to methyl bromide fumigation.Hortscience 47, 64-70.

Sanchez-Tellez S. Herrera-Cid R. Besoain-Canales X. Perez-Roepke L. M. Montealegre-Andrade J. R. 2013. In vitro and in vivo inhibitory effect of solid and liquid *Trichoderma harzianum* formulations on biocontrol of *Pyrenochaeta lycopersici*.Interciencia;.38(6):425-429.

Saresh, N.V (2013) Effect of Thickness of Polythene Sheet and Duration of Solarisation on Soil Temperature in Primary Nursery. Indian Forester, [S.l.], p. 58-60, jan. 2013. ISSN 2321-094X. Available at: http://www.indianforester.co.in/index.php/indianforester/article/view/29135 .

Sasanelli N., Dongiovanni C.,Santori A., and Myrta A.(2014) Control of. the root-knot nematode .*Meloidogyne incognita* by dimethyl disulfide (DMDS) applied in drip irrigation on melon and tomato in Apulia and Basilicata (Italy). Acta Hort. 1044:401-403.

Sasser J.N., Kirkpatrick T.L., Dybas R.A. (1982) Efficacy of avermectins for root-knot control in tobacco. Plant Disease 66:691-693.

Savigliano, R., Hanich, Z., Pugliese, M. and Pizano, M. (2014). High quality compost: a promising future for sustainable agro-industry in Morocco. Acta Hort. (ISHS) 1044:119-125

Schneider, S. M. and Hanson B.D. (2009). Effects of fumigant alternatives to methyl bromide on pest control in open field nursery production of perennial fruit and nut plants.*HortTechnology* 19(3): 526-532.

Schneider, S. M., Ajwa H., Trout T.J., and. Gao S.,. (2008). Nematode control from shank- and drip-applied fumigant alternatives to methyl bromide. *HortScience* 43(6): 1826-1832.

Schneider, S. M., Hanson B.D, Gerik J.S, Shrestha A., Trout T.J , and Gao S. (2009). Comparison of shank- and drip-applied methyl bromide alternatives in perennial crop field nurseries.*HortTechnology* 19(2): 331-339.

Schwarz D, Rouphael Y, Colla G, Venema J H. (2010). Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. *Scientia Horticulturae* 127, 162-171.

Shaw D.V., Gordon T.R., Larson K.D., Gubler W.D., Hansen J., Kirkpatrick S.C. (2010).Strawberry breeding improves genetic resistance to Verticillium wilt. *California Agriculture* 64(1), 37-41.

Shennan C., Muramoto J., Baird G., Daugovish O., Koike S., Bolda M. (2011). Anaerobic soil disinfestation: California. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions.San Diego, California USA.

Shennan C., MuramotoJ., Baird G., Fennimore S., Koike S., Bolda M., Daugovish O., Dara S., Mozzola M. Lazarovits G. (2012). Non-fumigant strategies for soil borne disease control in California strawberry production systems.Proc.Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions. Maitland, Florida USA.

Shennan C., MuramotoJ., Baird G., Koike S., Mazzola M. (2013). Optimizing anaerobic soil disinfestation for soilborne disease control Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions. San Diego, California USA

Shennan C., MuramotoJ., Koike S., Daugovish O., Mochizuki M., Rosskoph E., Kokalis-Burelle N. Butler D. (2010).Optimizing anaerobic soil disinfestation for strawberry production in Calofornia.Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions.Orlando, Florida USA.

Shennan, C., Muramoto, J., Lamers, J., Mazzola, M., Rosskopf , E.N., Kokalis-Burelle, N., Momma, N., Butler, D.M. and Kobara, Y. 2014. Anaerobic soil disinfestation for soil borne disease control in strawberry and vegetable systems: current knowledge and future directions. Acta Hort. (ISHS) 1044:165-175

Shinmura A. (2004) Principal and effect of soil sterilization method by reducing redox potential of soil. PSJ Soilborne Disease Workshop Report No.22, 2-12

Shinozaki T., Matsuzaki Y. and Yasunaga T. (2003). Control of Fusarium Wilt by Methyl Bromide Substitution in Strawberry. ?

Shrestha U., Ownley B., RosskophE.,ButlerD.(2013) . Optimization of amendment C:N ratio in an anaerobic soil disinfestation for control of *Sclerotium rolfsii.* Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions.San Diego, California USA.

Stoddard, C. S., Davis M;, Ploeg A.,, and Stapleton J;,. (2010). Methyl bromide alternatives show good potential for sweet potato hot beds. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions.pp 33-1 to 33-3. http://www.mbao.org/2010/Proceedings/033StoddardSPAW.pdf

Suchoff D.H, Frank J., Louws F.J,, Christopher C., Gunter J.R,, Randall Patterson R., (2013). On-farm grafted tomato trial to manage bacterial wilt. Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2013, San Diego, California, 89

Tanyolaç B., Akkale C. (2010). Screening of resistance genes to Fusarium root rot and Fusarium wilt diseases in F3 family lines of tomato (*Lycopersicon esculentum*) using RAPD and CAPs markers. *African Journal of Biotechnology* 9, 2727-2730

Tateya, A. (2009). Japan big effort to phase-out of methyl bromide by 2013. Annual international research conference on methyl bromide alternatives and emissions reductions, San Diego, California USA http://mbao.org/2009/Proceedings/006TateyaAJapanBigEffortstoPhaseofMethylBromide(090904).pdf

TEAP (2014).May 2014 Progress Report. Chapter XX: Interim evaluation of 2014 critical use nominations for methyl bromide. UNEP Nairobi, Kenya

TEAP(2011). Report of the Technical and Economic Assessment Panel.May, 2011. Ozone Secretariat, UNEP, Nairobi

Thangarajan R., Bolan N.S.,Tian G., Naidu R., Kunhikrishnan A. (2013). Role of organic amendment application on greenhouse gas emission from soil.*Sci Total Environ.*465, 72-96.

Thomas H., Legard D., Sjulin T., Rowe D., Reddy S., Fennimore S., Serohijos R., Low C., (2011). Production of strawberry in substrate. In: Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, California USA.

Titiz, Ş. (2004). Modern Seracılık, Yatırımcıya Yol Haritası. Antalya Sanayici ve İş adamları Derneği.Retma Yayıncılık, Antalya (Modern Greenhouses, Road map for Investors. Association of Antalya Industrialists and Businessmen. Retma Publication, Antalya.)

Tomlin C.D.S. (1997) The pesticide manual, 1997. British Crop Protection Council 49.

Triky-Dotan S., Austerweil M., Steiner B., Peretz-Alon Y., Katan J., Gamliel, A. (2009), Accelerated degradation of metham-sodium in soil and consequences for root-disease management. Phytopathology 99:362-368.

TUİK (2009).Turkey Statistic Foundation (TUİK) (State Institute of Statistics).Agricultural structure and production. Publication no. 2895., Ankara, Turkey.

Turhan A., Ozmen N., Serbeci M.S., Seniz V. (2011). Effects of grafting on different root stocks on tomato fruit yield and quality. *Hort. Sci. (Prague) ,38*,142–149

Ueno K.i, Kaneko K., Taniguchi E. and Nagasawa S. (2006). Control of Fusarium Wilt and Nematode on Strawberry by Soil Reduction in Yamagata Prefecture.*Ann. Rept. Plant Prot. North Japan* 57:62-64

UNEP. (2014). Phasing-out Methyl Bromide in A5 Countries – A success story and its challenges; UNEP Division of Technology, Industry and Economics (UNEP DTIE) OzonAction Programme; available at http://www.unep.fr/ozonaction/information/mmcfiles/7674-e-Phasing_out_Methyl_Bromide_in_developing_countries.pdf

UNEP/MLF/MoE/UNIDO.(2004) Methyl Bromide alternatives project for the strawberry sector in Lebanon.

UNIDO (2008) National phase-out of MB in horticulture and commodities fumigation in Egypt. Project EGY/FUM/38/INV/86

UNIDO (2008).National MB phase-out program in Mexico–Project MP/MEX/08/001/1158-2009

UNIDO (2010). Technical assistance for the national phase-out of MB – Chile

Vallad, G.E.,Boyd N., Noling, J. (2014). A comparison of alternative fumigants to methyl bromide for Florida tomato. , MBAO, Annual international research conference on methyl bromide alternatives and emissions reductions, Nov 4-6, 2014, Orlando, Florida

Vallad G.E., Boyd N. (2013). An allyl isothiocyanate biopesticide for managing weeds, pests, and pathogens in soil. In: 2013 annual international research conference on methyl bromide alternatives and emissions reductions. methyl bromide alternatives outreach, San Diego, California, Nov 4-6, 2013.

Van Wambeke E. (2007). Combinations of reduced rates of 1,3-dichloropropene and dazomet as a broad spectrum soil fumigation strategy in view of methyl bromide replacement. Commun. Agric. Appl. Biol. Sci.72, 61-70.

Van Wambeke E., Ceustermans A., De Landtsheer A., Coosemans, J. (2009). Combinations of soil fumigants for methyl-bromide replacement. Commun. Agric. Appl. Biol. Sci. 74, 75–84.

Verdejo-Lucas S., Blanco M., CortadaL., Sorribas F.J., (2013). Resistance of tomato rootstocks to *Meloidogyne arenaria* and *Meloidogyne javanica* under intermittent elevated soil temperatures above 28 C .*Crop Protection*, *Volume 46*, *April 2013*, *Pages 57-62*

Vervoort M.T. W., Vonk J. A., Brolsma K. M., Schutze W., Quist C. W., de Goede R.G. M., Hoffland E., Bakker J., Mulder C., Hallmann J., and Helder J., (2014). Release of isothiocyanates does not explain the effects of biofumigation with Indian mustard cultivars on nematode assemblages. In: Soil Biology & Biochemistry, 68, 200-207.

Villeneuve F., Latour F., Théry T., Steinberg C., Edel-Hermann V., PitratM. and Daunay M..C. (2014). The control of soil borne vascular diseases: limits of genetic resistance of cultivars and rootstocks for controlling F*usarium oxysporum* f. sp. *melonis* (melon) and V*erticillium* sp. (eggplant). Acta Hort. (ISHS) 1044:57-65

Vitale A., Castello I., Cascone GD, Emilio A., Mazzarella R., Polizzi G. (2011). Reduction of corky root infections on greenhouse tomato crops by soil solarisation in South Italy. *Plant Disease.* 95,(2) 195-201.

Vitale A., Castello I., D'Emilio A., Mazzarella R., Perrone G., Epifani F., Polizzi G. (2013). Short-term effects of soil solarisation in suppressing *Calonectria* microsclerotia; Plant and Soil Journal; July 2013, Volume 368, Issue 1-2, pp 603-617

Wahb-Allah M. A. (2014).Effectiveness of grafting for the improvement of salinity and drought tolerance in tomato (*Solanum lycopersicon* L.).*Asian Journal of Crop Science* 6, 112-122

Walters, T., M. Particka, Zasada I;,, and. Pinkerton J.N. (2011). Productivity and economics of methyl bromide alternatives for raspberry nursery.Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions.http://www.mbao.org/2011/Proceedings/29WaltersT.pdf

Wang Q. J., Ma Y., Wang G. F., Gu Z. G., Sun D., An X., and Chang Z.Z., (2014). Integration of biofumigation with antagonistic microorganism can control Phytophthora blight of pepper plants by regulating soil bacterial community structure. In: European Journal of Soil Biology, 61, 58-67.

Wang Q., Yan D., Mao L., Ma T., Liu P., Wu Z., Li Y., Guo M., Cao A. (2013) Efficacy of 1,3-dichloropropene plus chloropicrin gelatin capsule formulation for the control of soilborne pests. Crop Protection 48, 24-28.

Westerdahl ., L. D., Chiller C.T, (2014).Nimitz (MCW-2) for management of root-knot nematode on annual crop. In: Gullino M.L;, Puglise M. and.Katan J., eds.;Proceedings of the eighth international symposium on chemical and non-chemical soil and substrate disinfestation, Acta Horticulturae, 1044, 353-358

Westerdahl B.B and Beem L.W., (2013). New products for nematode management on annual crops in california . Proceedings of the international research conference on methyl bromide alternatives and emissions reductions . San Diego, California, November 4-6, 7

Whitaker V.M., Chandler C.K., Santos B.M., Peres N.A., Nunes M.C., Ploto A., Sims C. (2012). "WinterstarTM) 'FL05-107' Strawberry. HortiScience 47, 296-298

Wu H., Wang C.J., Bian X.W., Zeng S.Y., Lin K.C., Wu B., Zhang G.A., Zhang, X. (2011). Nematicidal efficacy of isothiocyanates against root-knot nematode Meloidogyne javanica in cucumber. Crop Protection,30, 33-37.

Xiaoxue J., Kang Q., Sa D., Hongyan W., Xiaoming X., Kaiyun W., (2013).Effects of 1,3-dichloropropene plus chloropicrin on weed seed germination . Crop Protection, 45, 1-5

Yamada, K., *et al.* (2003). Control of Fusarium wilt on strawberry by Soil Reduction.*Annual Report of the Kanto-Tosan Plant Protection Society* 50, 49-52

Yaseer S. M., Mohamad A.M. , Mahamud S. and Khadzir D., (2012). Effects of substrates on growth and yield of ginger cultivated using soilless culture. J. Trop. Agric. and Fd. Sc. 40(2), 158-168.

Yates S.R., Ashworth D.J, Yates M.D., Luo, L. (2011). Active Solarisation as a Nonchemical Alternative to Soil Fumigation for Controlling Pests; Soil Sci. Soc. Am. J.;. 75:9–16.;

Yasuaki, M. (2012) Construction of a Cultivation Manual for Ginger in Open Fields without Methyl Bromide in Kochi Prefecture Plant Protection 66(12): 24-28

Yilmaz S, Celik I, Zengin S. (2011). Combining effects of soil solarisation and grafting on plant yield and soil-borne pathogens in cucumber. *International Journal of Plant Production* 5(1), 95-104

Yilmaz Y.B., Tunaz, H. (2013). Fumigant toxicity of some plant essential oils and their selected monoterpenoid components against adult American cockroach, *Periplaneta americana* (Dictyoptera: Blattidae). Turkiye Entomoloji Dergisi-Turkish Journal of Entomology 37, 319-328.

Yilmaz, S., Firat, A. F., Mutlu, N. and Surmeli, N. 2005. Recent developments of the vegetable production system in Turkey. Increasing Market-oriented Vegetable Production in Central Asia and the Caucasus through Collabrative Research and Development. Workshop Proceedings; 25-27 April 2005, Tashkent Uzbekistan.

Yilmaz, S., Gocmen, M., Ünlü, A., Aydinşakir, K., Mutlu, N., Baysal, Ö., Sayın, B., Celikyurt, M.A., Fırat, A.F., Çelik, İ. Aktaş, A., Öztop, A., Zengin, S., Devran, Z. and Tekşam, İ., (2008). Phasing out of methyl bromide in Turkey: Final Report, ISBN 9789754072549, 156 p., Antalya.

Yilmaz, S., Ünlü, A., Göçmen, M., Aydinşakir, K., Sayin, B., Kazas, S., Çelikyurt, M.A., Aktaş, A. and Zengin, S (2007). Alternatives to methyl bromide for cut flowers in Turkey. In: Annual International Conference on Methyl Bromide Alternatives and Emission Reductions. San Diego, CA, USA p. 48-1-3.

Yilmaz, S., Ünlü, A., Gocmen, M., Mutlu, N., Aydinşakir, K., Fırat, A.F., Kuzgun, M., Celikyurt, M.A., Sayın, B. and Çelik, İ. (2006). Phase out of methyl bromide for soil fumigation in protected horticulture and cut flower production in Turkey. Final Report, 2006. Antalya, Turkey.

Yonemoto K, Hirota K, Mizuguchi S., Sakaguchi K.,(2006) . Utilization of the sterilization by soil reduction in an open air field and its efficacy against Fusarium wilt of strawberry. Proc. Assoc. Pl. Protec. Shikoku, No41: 15-24

Yücel S., Ozarslandan A., Can C. and Gunaçti H. (2014).Case studies and implications of chemical and non-chemical soil disinfection methods in Turkey. Acta Hort. (ISHS)

Zanon M.J., Guitierrez L.A., and Myrta A.(2014). Spanish experiences with dimethyl disulfide (DMDS) on the control of root-knot nematodes, *Meloidogyne* spp., in fruiting vegetables in protected crops Acta Hort. 1044:421-425.

Zanón MJ, Jordá C. (2008). Eradication of *Clavibacter michiganensis* subsp. *michiganensis* by incorporating fresh crop debris into soil: preliminary evaluations under controlled conditions. *Crop Prot*. 27, 1511-1518.

Zasada, I.. Walters A.T.W., and Hanson B.D.,. (2010). Challenges in Producing Nematode- and Pathogen-free Fruit and Nut Nursery Crops in the United States. Outlooks on Pest Management 21:246-250.

Zavatta, M., Shennan, C., Muramoto, J., Baird, G., Koike, S.T., Bolda, M.P. and Klonsky, K. (2014). Integrated rotation systems for soilborne disease, weed and fertility management in strawberry/vegetable production. Acta Hort. (ISHS) 1044:269-274

Zveibil A, Mor N;, Gnayem N;, , and Freeman S. 2012 Survival, Host–Pathogen Interaction, and Management of *Macrophomina phaseolina* on Strawberry in Israel . Plant Disease ,96:2, 265-272

Zveibil A., Freeman S. (2009). Methods for detection of soilborne pathogens affecting strawberry in Israel.ActaHorticulturae 842, 191-194.

Zveibil A., Freeman S.(2005). First report of crown and root rot in strawberry caused by *Macrophomina phaseolina* in Israel. Plant Disease, 89, 1014.

6

Chapter 6. Alternatives to methyl bromide for structures and commodities

6.1. Introduction

Parties and scientists around the world continue to conduct research aimed at identifying and adopting alternatives to MB for controlling pests causing problems in the structures and commodities sectors. The previous MBTOC Assessment Report (MBTOC, 2011a) includes a chapter on the use of MB alternatives in structures and commodities, which considers about 200 new references published between 2011 and 2006. Further, the MBTOC Assessment Reports of 1994, 1998, 2002 and 2006 refer to research and results which were current at the time when those reports were published. Information contained in these reports is still relevant and should be considered by Parties interested in feasible and available alternatives to MB for structures and commodities. All assessment reports are all available on the Ozone Secretariat homepage. In addition, progress reports published yearly by TEAP (2009; 2010ab; 2011; 2012) and its MBTOC present overviews on the MB phase-out, successful alternatives, remaining challenges and others.

This chapter discusses progress achieved in replacing controlled uses of MB in structures and commodities and analyses remaining challenges in some particular circumstances and sectors (inclusing regulatory issues), which impact the total phase-out. More detailed information is included for those specific uses of MB that have been exempted under the Protocol due to particular difficulties in finding and implementing effective alternatives for such uses.

6.2. Regulatory issues

Since the last MBTOC Assessment Report was published (MBTOC, 2011a), some changes have taken place in relation to the registration of suitable alternative chemicals.

The registration of chemicals for pest control, including MB, is under continuous review in many countries. In Australia and Canada for example, sulfuryl fluoride (SF) is under a re-registration process ; this directly impacts the Canadian mill industry as there is no food tolerance for SF in Canada, meaning that all food products have to be removed from the mill if it is to be SF treated. The lengthy US proposed regulation discusses both the health assessment of residues resulting from the use of SF in structures and commodities, and the legal basis and issues resulting from a proposal to phase out its use. Excerpting short sections of this lengthy regulation can lead misunderstandings so Parties may want to review the entire regulation (EPA 2011).

Fluoride presence in the diet is largely regional, as it concentration is influenced by naturally occurring fluoride (in soils, impacting water), by fluoride additions to drinking water, and to a much lesser extent by fluoride residues resulting from the use of SF as a fumigant. In 2010, the US EPA proposed a regulation on sulfuryl fluoride, which is part of a range of actions to reduce the incidence of fluoride in the diet of some sub-sectors of the US population, particularly children. The US reported to MBTOC in its CUNs that its assessment of the situation is on-going and the current registrations for sulfuryl fluoride have not changed.

Australia on its part has addressed this issue and reassured the public that fluoride presence in the diet is not a problem in that country and that therefore, the approval of SF for pest control in structures and commodities will not be impacted by the proposed US regulation. Canada has not so far established a tolerance for SF contact with food. In Europe, accessibility of SF has been reduced recently and currently it can only be used on empty food processing structures including mills and for dried fruit. Food tolerances in commodities have been reduced to impracticable levels for pest control. Complete egg control has been withdrawn from the label in some countries.

Further regulatory news relate to progress made by Japan in the implementation of necessary logistical and training requirements following its registration of methyl iodide for control of fresh chestnut pests. As part of their CUN of 2011, Japan presented a full phase out plan for the use of MB in chestnuts by 2015.

France and some Baltic countries have registered the Indian phosphine releasing product of United Phosphorous.Cylinderized phosphine (ECO_2 and Vaporphos) has been registered in Thailand, Indonesia, the Philippines, Australia, New Zealand, Papua New Guinea and Turkey. The process of registration is still ongoing in Singapore.

6.3 Update on progress in research into methyl bromide alternatives for commodities and structures

Many avenues of research have been pursued in the attempt to find realistic alternatives to MB for the remaining commodity and structural treatments conducted worldwide, as well as and in quarantine or preshipment situations (Ducom, 2012). These include studies on alternative fumigants such as phosphine, sulphuryl fluoride and ozone, on controlled atmospheres with elevated temperature or raised pressure, on microwave, radio frequency or ionizing radiation, or on heat. The pest control options available for use in the post-harvest commodity and structure area have recently been reviewed by Bell (2013; 2014a, b). Ducom et al. (2014) give an overview on the French and German (European) perspective of stored product disinfestation including the use of phosphine, inert atmosphers and contact insecticides. The following paragraph highlight some important findings from research conducted on alternatives to MB for structures and commodities in various countries around the world.

Research on phosphine has concentrated on combating the spread of resistance by studying the fate and effect of resistant genes in the pest population (Campbell, 2010; Ridley *et al*., 2012; Kaur *et al*., 2012; Daglish *et al*., 2014), and on factors improving the performance of phosphine fumigations (Beckett *et al*., 2010; Ridley *et al*., 2011; Shi *et al*., 2012; Nayak, 2012; Asher, 2012; Bridgeman and Collins, 2012; Newman *et al*., 2012abc).

Research on sulfuryl fluoride has followed requirements for optimum efficacy in treating timber and structures to control pests (Ren *et al*., 2011; Tsai *et al*., 2012; Chayaprasert *et al*., 2012) and on its possible combination with other toxicants (Riudavets *et al*., 2014) or heat (Hartzer *et al*., 2010a).

Practical methods using **ozone** to control pests in silos has received attention (Hardin *et al*., 2010; Hasan *et al*., 2012; McClurkin *et al*., 2013) and **controlled atmosphere** performance at raised temperature (Sen *et al*., 2010; Son et al., 2012) or raised pressure (Noomhorm *et al*., 2013) has seen some progress. The threshold levels for toxic action of various atmospheres in terms of gas concentration and time of exposure have recently been reviewed by Bell (2014c).

The prospects of using radiation energy sources for post-harvest pest control has received increasing attention in recent years, particularly in the area of **microwave** (Purohit *et al*., 2013; Manickavasagan *et al*., 2013) or radio wave frequencies (Jiao et al., 2012; Wang et al., 2013). The use of ionizing radiation in this field has recently been reviewed by Hallman (2013). The use of heat for disinfestation of commodities or structures, either as an enhancement for other control procedures (Sen *et al*., 2010; Akan and Ferizli, 2010; Fields, 2012) or by itself (Subramanyam et al., 2012; Campolo *et al*., 2013) has continued to receive attention in the attempt to raise efficacy levels to that achieved by methyl bromide.

6.4. Fields of application (product/location) where MB has been or will shortly be phased out

6.4.1 Alternatives to MB for rice, [empty] flour mills and dried fruits

For several decades, some fields of application within the section of disinfestation of stored products or empty structures remained without accepted alternatives in some countries. Some Parties claimed that despite robust efforts to replace MB in these fields they had been unable to identify economically equally feasible and equally effective alternatives or to adopt those that had been implemented in other countries in similar situations. The main constraints cited were the high costs associated to the phase in of alternatives, the non-availability of alternative chemicals due to lack of registration and the absence of suitable premises or fumigation buildings in which to apply alternatives. These particularly difficult sectors included:

- Australia's rice processors
- Millers in Canada
- Millers in the United States
- Dried fruit producers in the US

As of 2015 however, all these postharvest uses of MB have been phased out in the non-A5 Parties listed above and no CUNs have been submitted for these uses for

2016. Australia is confident to turn to phosphine as replacement gas and is building the appropriate structures. Some carbon dioxide is also considered as an alternative chemical for disinfestation.

Besides application of heat, SF is the main chemical alternative for disinfestation of empty food and feed plants wherever it is registered for this use. Ethyl formate is used on some commodities in New Zealand and Australia.

6.4.2 Alternatives to MB for treating dates

In its 2006 and 2010 assessment reports, MBTOC described difficulties in finding effective MB alternatives for high moisture dates. Since that time, date producing countries have improved harvesting methods, logistics, pest control treatments and exporting conditions and all these measures are contributing to reducing date spoilage and improving date quality. No CUNs have been submitted for this sector by non-A5 Parties for several years. The alternatives implemented, together with the specific situation of high moisture dates, at one point indicated as critical in A-5 countries producing dates are analysed in detail in the following sections.

6.4.2.1. Decision XV/12 (1): High moisture dates

In 2003, MBTOC noted that technically and economically effective alternatives to MB had not been identified for disinfestation and stabilisation high-moisture dates. In response to this, and at the request of some North African countries, the15th Meeting of the Parties issued Decision XV/12, which states:

> "… That the Implementation Committee and Meeting of the Parties should defer the consideration of the compliance status of countries that use over 80% of their consumption of methyl bromide on high-moisture dates *until two years after the TEAP formally finds that there are alternatives to methyl bromide that are available for high-moisture dates…"*

Since that date, date producing countries have worked to develop technically and economically feasible alternatives and although the MBTOC its 2006 and 2010 Assessment Reports continued to identify hurdles in the implementation of alternatives to MB for disinfestation of high-moisture dates, recent MBTOC reports indicate large progress. In fact, the TEAP/ MBTOC May 2013 Progress report recognises technically and economically feasible chemical (phosphine, phosphine/CO_2, ethyl formate, sulfuryl fluoride) and non-chemical treatments (heat, cold, controlled atmospheres, IPM in the field and in the packing houses) that can be used to effectively replace MB for this use. Alternatives are available for all varieties of dates, including so-called high moisture dates, c.v. Deglet Noor. The latter are of particular importance in Algeria and Tunisia. Optimum choice of treatment is dependent on the variety and particular circymstances, including local pesticide registration.

Phoenix dactylifera has been a staple food in the Middle East and North Africa for thousands of years. A high proportion of the world's date production is concentrated in a few countries in this region : Egypt, Iran, Saudi Arabia, Pakistan, Iraq, Algeria, the United Arab Emirates, Sudan, Oman and Morocco, account for about 90% of the total world production.

Pest infestations in the field pose serious post harvest problems for all date varieties. Historically, dates have been disinfested prior to storage with ethyl formate, ethylene dibromide or ethylene oxide, and more recently with MB in some date producing regions such as Tunisia, Israel and the USA. Fumigation with MB forces a high proportion of larvae and adults to emigrate from the fruit before they succumb, which is essential to meet some religious and food quality requirements.

In the USA, all date types including Deglet Noor are left to dry on the palm to a moisture content of about 23 %, which is safe for storage at ambient temperatures without spoilage from moulding or fermentation. In Arizona, MB was never used for date disinfestation and the California date sector has now adopted alternatives to methyl bromide, replacing significant quantities used previously with mostly phosphine treatment, and to a lesser extent SF. Recent research reports good efficiency of Ethyl Formate, however this fumigant is not registered on dates in the United States.

Israel has adopted heat treatment and ethyl formate. During the heat treatment, insects exit the fruit trying to escape the high temperatures, ensuring that treated dates do not contain dead insects. Ethyl formate in carbon dioxide (Vapormate^{TM}) was successfully tested and is widely adopted for date disinfestation.

In Algeria and Tunisia, Deglet Noor dates are harvested when the moisture content is between 35 and 40% and should be treated and stored in cold rooms. Phosphine fumigation has largely replaced post harvest MB fumigation in Algeria, Tunisia, Egypt, Jordan, UAE, KSA and other countries. The fumigant is either supplied by tablet formulations or a phosphine generator. Dates treated by this process include high-moisture dates e.g., cv'Deglet Noor'referred to in Decision XV/12. Two surveys conducted in 2011 in Tunisia showed that 60 % of the exported dates were fumigated with phosphine and 40 % with MB and other alternatives. The main fumigant used on all types of dates is phosphine ; of 36 packing houses surveyed, 23 used phosphine, and the rest used other alternatives, including cold, cold+ phosphine and heat. Only 2 stations out of the 36 still continued to use MB. No decrease in date quality was reported by the exporting/importing countries. However, some chemical alternatives are not yet available in some countries.

According to Tunisian law, MB fumigation is no longer allowed in newly built packing houses. Application has been made for registration of the ethyl formate/CO_2 fumigant formulation for dates in Tunisia and controlled atmosphere treatments are under consideration. Further, essential oils are under investigation for their suitability of use against the carob moth *Ectomyelois ceratoniae* (Jemâa *et al.,* 2012; 2013)

In view of this situation, MBTOC believes that the high moisture dates issue is solved and has presented information to the Parties in this respect, in its Progress Reports and during Montreal Protocol meetings of the past two years.

6.5 On use of methyl bromide for dry cure pork products in Southeast US as the remaining field of MB application without available feasible alternatives

In some southern US states, typified by at least one season of cool but not freezing weather, and by warm days and cool evenings in another season, and where historically a major salt source was nearby, a natural, cured pork product was developed, utilizing weather changes, salt, sometimes sugar and the most basic of chemical curing agents. According to Kurlanski (2002), there is a 'pork belt' around the globe where the similar climatic conditions and regional availability of salt resulted in different, but similar, parallel development of natural cured pork products. So, natural regional cured pork products were developed, for example, in China, Italy, Germany, Spain, and parts of the Southern United States. There are differences in the pork products produced in these regions resulting from variances in local weather patterns and resulting from historical differences in processing methods and use of additives.

Although most other cured pork methods have been modernized, this tradition of natural and lengthy pork curing continues today in those regions. The pork products have different names, and in the United States this Southern dry cure pork product is often called Country Ham even though it might not be just the leg portion. Production of Country Ham - while small in the context of total cured pork production in the United States-, is not inconsequential. It has been reported to MBTOC that 45 Country Ham facilities produce three to five million hams each year, and these may require fumigation against pests.

All these natural pork products are subject to pest infestation, in part because of the lengthy storage time required for flavour development. The length and situation of the storage rooms and difference in type of curing agents can impact the extent, types and balance of pest infestation of that region's pork product. However, in a survey of American cured pork producers reported to MBTOC, the most significant factor in the development of pest infestation is length of storage. Hams that were stored for longer than six months were more often infested than those stored less than six months. Resolving this is not simply a matter of shortening storage time, however, since storage times of greater than five months is considered necessary for the product to achieve the correct flavour profile and the longer stored hams are considered better quality.

The pests most commonly reported are red-legged ham beetles *Necrobia rufipes* and ham mites *Tyrophagus putrescentiae*. The red-legged ham beetle reportedly causes 50-60% of the infestations and the ham mite causes 60-70% of the infestations. Of these, the most difficult to control are mites. Mites are acknowledged to be very difficult to kill with phosphine, and in tests of the effectiveness of SF in 2008, control of the ham mites required three times the US legal limits of SF (Phillips, *et al*., 2008).

Currently in the United States, there are three fumigants registered to control the pests of Southern cured pork: MB, phosphine and SF.Research in the US can be summarized as first improving integrated pest management and sanitation approaches.

Then, lab scale studies were conducted to determine if the target pests were killed by the approved fumigants, and other known methods of pest control. The approaches successful at lab scale were trialled at larger scale.

Improving IPM and sanitation was difficult to manage in the largely traditional Southern cured pork storage setting. US researchers noted that improved control of pest harbourage in the exterior of the facilities has been conducted. Some companies eliminated grass, trees, and shrubs from their buildings and replacing them with gravel, as suggested by researchers in 2008, to reduced harborage for pests outside their aging houses. These efforts have reduced their use of methyl bromide, but have not eliminated the need to disinfest their dry, cured pork products. Sanitation of storage rooms and equipment in between production runs has reportedly been improved. These aspects are largely meat processing approaches, rather than entomology approaches.

Entomologists have conducted tests to determine if phosphine treatments could be effective against ham pests. Early lab scale tests determined some effectiveness of phosphine against the target pests. Investigators achieved 100% mortality of all life stages of red-legged ham beetles and ham mites with 48 hours exposure at 400 ppm and 1000 ppm of phosphine, respectively (Sekhon et al., 2009b; Sekhon et al., 2010c). In addition, residual phosphine concentrations in dry cured hams that were fumigated for 48 h at 1000 ppm were below 0.01 ppm, the legal residual limit in stored food products (Sekhon et al., 2009b; Sekhon et al., 2010c); and consumer panellists could not detect differences between control and phosphine fumigated samples at 1000 ppm (Sekhon et al., 2009b; Sekhon et al., 2010c). Therefore, phosphine was considered a potential alternative to methyl bromide for controlling arthropod pests of Southern dry cured hams. Further testing with a greater number of mites indicated that a greater concentration of phosphine (>1000 ppm) is likely necessary to kill substantial mite infestations.

These lab scale tests using phosphine led to fumigation trials conducted in 2011 in 30 m^3 shipping containers intended to simulate dry cure aging ham houses at phosphine concentrations ranging between 1000 ppm - 2000 ppm and exposure times of 48 or more hours. Temperature was measured in the ham houses during fumigation and twenty jars with samples of *T. putrescentiae* bioassay and ten samples of *N. rufipes* were placed in each shipping container for each trial. Ten dry cure hams were hung from racks in shipping containers to simulate dry cure aging conditions. Five of these hams were used for mite inoculation and the other 5 hams were used for sensory analysis and phosphine residue testing. The lean portion of the dry cure hams that were used for inoculation was also inoculated with a mixed culture of approximately 1000 mites. Phosphine gas was produced in the shipping containers using magnesium phosphide cells that reached target fumigation doses at between 8 to 12 hours after the fumigation was started.

The post-embryonic mite mortality was 99.8% in the bioassays at two weeks post fumigation when 2000 ppm phosphine was achieved, but the eggs on either the hams or in the bioassays were not controlled, even at concentrations as great as 2000 ppm. If the pest eggs are not controlled the product would be infested again within days.

Investigations presented at 2010 MBAO at temperatures of 20°C or greater, all life stages of red-legged ham beetles were controlled in all fumigation trials. Variations in test conditions indicated that temperatures and exposure time need to be optimized for fumigation since 48 hours was not long enough to control ham mites at 2000 ppm. Ambient temperatures below 15°C decreased the effectiveness of the fumigation against both ham mites and red legged beetles.

For the sensory tests, ham slices were oven baked to an internal temperature of 71°C and served to trained panellists. Sensory tests indicated that trained panellists could not determine differences ($P>0.05$) between phosphine treated dry cured hams and non-fumigated hams. In addition, residual phosphine concentration was below the legal limit of 0.01 ppm w/w in ham slices that were taken from phosphine fumigated hams.

Following this work, one phosphine fumigation trial (Zhao *et al* 2012b) was conducted in a 1,000 m^3 (36,000 cubic feet) processing facility at 1600 ppm. Ham mite assays with live mites were distributed throughout the aging room. After 48 h of fumigation (26°C, 70-80 % RH), there were no living ham mites in the assays. However, phosphine fumigation corroded the electrical switches to the fans, and these switches had to be replaced. In addition, the research needs to be repeated when many hams are infested with mites to determine if it is effective in real world situations. In addition, if phosphine is going to corrode and incapacitate electrical equipment, it may not be adaptable to the industry.

Previously CUNs from the US had described the failure of SF, carbon dioxide, and ozone to control ham mites and red legged ham beetles. Also the US previously reported the results of low pressure and low oxygen concentrations on ham mites under laboratory settings, which took too long to be a viable option at this time.

The results of investigations with carbon dioxide, phosphine, methyl bromide and ozone treatments on *Tyrophagus putrescentiae*, ham mite, and *Necrobia rufipes*, red-legged ham beetle, were presented by Sekhon et al., 2009a, b; Phillips et al., 2011, Sekhon et al., 2010b, 2010c). The studies included eggs and a mixture of adults and nymphs of mites and eggs, large larvae, pupae and adults of beetles. The experiments were conducted for variable times at 23°C at various concentrations of carbon dioxide, phosphine, methyl bromide and ozone. The investigators achieved mortality of all life stages of mites with a content of 60 % carbon dioxide with 144 h of exposure (Sekhon et al., 2009a; Sekhon et al., 2010b). However, fumigation with carbon dioxide would likely not be applicable since ham structures are not air-tight and 144 h is too long of a time to fumigate the hams.

MBTOC explained that other regions employed hot dips of lard or oil to control pests of similar cured pork products. MBTOC also suggested physical exclusion by means of fine mesh or air blowing out of the curing chamber could help avoid mite infestation. Lehms et al. (2012) showed that nets of 30 µm were sufficient to keep out all stages of the mite *Tyrophagus putrescentiae*. This needs to be confirmed in commercial process and to resolve practical questions. For example, the mesh could be used to form a shroud over the hanging shelves of hams to keep mites infesting the aging room from attacking the clean hams. MBTOC suggested that the Party examine these possibilities, and examine increasing the temperature during fumigation to enhance effectiveness; the Party informed MBTOC in 2013 that it is doing this.

Following MBTOC's suggestion to try hot dips, US researchers began a series of laboratory experiments (Zhao et al 2012a) in which 1-cm square cubes of ham were dipped into a test compound of a given concentration for 1.0 minute and then placed in a ventilated glass jar and inoculated with 20 adult mites. Jars were held for 14 days to allow for mite reproduction and population growth, after which the total number of mite adults and nymphs were counted and compared to numbers produced on other treated ham pieces and on control hams dipped in water only. Three groups of experiments were conducted that compared common food oils, synthetic polyols and common legal food preservatives. Among oils tested, 100% lard from pork fat completely prevented mite reproduction on treated ham pieces, while vegetable oils such as olive, corn and soybean had minimal effects on mites. Of the polyols, glycerol had little effect on mites while propylene glycol at 100% or 50% prevented mite reproduction. Other short-chain diols had significant effects on mite reproduction. Of the other food preservatives tested, the various salts of sorbic and propionic acids were effective at preventing mite growth when applied as 10% solutions in water. Research so far suggests that approved food oils and synthetic food preservatives show potential for protecting dry cured hams from mite infestation, and future work will need to address the effects of these additives, if any, on the quality of hams during the aging process and on consumer acceptability.

In additional studies (Zhao *et al*., 2012b), ham slices and 1-cm square cubes were dipped directly into either mineral oil, propylene glycol, 10% potassium sorbate solution or glycerin for 1 minute and dripped on a mesh colander for another minute. Lard was applied directly by rubbing a thin layer to cover the whole piece. Ham cubes (2.5 cm ×2.5 cm × 2.5cm) were used for the mite infestation study. During the study, 20 mites (mostly adult female) were placed on one cube of ham which was placed in a ventilated, mite proof glass container and incubated for 21 days at 27ºC and 70% relative humidity. Mite populations on ham cubes were counted every week. Coatings on ham slices were washed off before cooking. Ham slices were oven baked to internal temperature of 71°C and served to trained panellists for sensory difference from control tests.

Results indicated that both lard and propylene glycol were effective ($P<0.05$) at controlling mite reproduction. No difference was detected in sensory characteristics between control ham slices and samples treated with food grade ingredients. In addition, potassium sorbate and mineral oil did not inhibit mite reproduction but slowed mite growth ($P<0.05$) when compared to the control, and glycerin was ineffective at lowering mite counts ($P>0.05$) when compared to the control.

The majority of research that has been conducted on use of food grade ingredients with meat products has been to prevent water loss and reduce rancidity of meat products. However, a finished ham product needs to lose at least 18% of its original weight during aging. At the same time, the unique flavors of dry cured ham are caused by proteolysis and lipolysis with the presence of oxygen. In this case, water vapor permeability of the films and coatings needs to be considered when choosing a proper coating. Current and future research is being conducted to develop a cost-effective food grade coating with high oxygen and water vapor permeability.

Based on the research studies described above (Zhao *et al*., 2012a), the active ingredients that show the most promise as potential methyl bromide alternatives are propylene glycol, butylate dhydroxytoluene (BHT), and lard. Propylene glycol (PG) is likely the most feasible food-grade ingredient that could be used to control ham mites but is also relatively expensive. BHT is effective at controlling mites on ham pieces at a concentration of 10 %. However, 0.01 % BHT (by fat percentage) is the acceptable level in some meat products. This makes it unlikely that it would be accepted for use, but may have application if it can be washed off the surface and there is less than 0.01% BHT in the finished product. Lard was effective at controlling mites on ham pieces. However, use of lard may prevent moisture loss and transmission of oxygen which would prevent the preservation and flavor development of the ham. However, these 3 ingredients need to be evaluated on whole hams for their ability to control mite infestations. In December of 2012, research was started on whole hams such that the hams are treated with BHT, lard, or propylene glycol. Propylene glycol will be used in food-grade gel coatings to determine if incorporating PG in a gel will prevent evaporation of the PG and prolong its effectiveness at controlling mites. US researchers indicated they will also work with processors to implement PG and other food grade products that may control mites in their plants to determine their impact in industrial settings.

Part of the problem of conducting research on ham mites is the practical difficulty of assessing their presence and counting them due to their small size of less than 0.4 mm.To help resolve this problem, Zhao et al. (2012b) developed a mite trap based on the basic design of a trap first developed in England. This trap consists of a 90 mm disposable plastic Petri dish that is painted black on the entire outer surface. Around the sidewall of the dish are eight evenly spaced holes, approximately 0.5 mm in diameter, at 2 mm above the bottom of the dish for entry of responding mites. A food bait was placed inside the middle of the dish and was a 25 mm diameter circular plug of mite diet, approximately 10 mm high. Mite diet was composed primarily of ground dog food with yeast, glycerin, anti-fungal agent and gelled with 2% agar. Mites respond to the baited dishes, enter the holes in the side wall, and feed to the diet plug where they mate and lay eggs. Laboratory studies confirmed that traps baited with diet were highly attractive to mites compared to unbaited traps. A study was initiated to monitor mite populations in which twenty traps were distributed evenly throughout each of three different ham production facilities for consecutive one-week periods. Mite numbers lured to traps varied from zero to several hundred in one week, and seasonal trapping determined that certain areas of facilities had higher mite activity than other areas. Traps confirmed that fumigation in certain circumstances caused severe reduction in mite populations, and showed that mites would slowly increase activity following fumigation.

In summary, to MBTOC's knowledge no other similar traditional cured pork product is disinfested with methyl bromide. Although there had been some promising results of potential alternatives for mite control in dry cure hams at lab scale, currently, no fully effective treatment has been found which controlled the target pests at commercial scale for Southern cured pork production.

This specific kind of ham presents in some areas of the US - where it is especially preferred as breakfast food - limits to exclude or control pest arthropods like the mite and some beetles. The old ham houses in use and the production and strage procedures ensure on one side the typical taste and organoleptic quality of this food. On the other hand, replacement of MB fumigation within this system can obviously not be performed without changing the quality of the ham. The constraints to replace MB here are well documented in previous reports. Despite robust research supported by the US government and intensive consultations with MBTOC, still no viable alternative has been found to replace methyl bromide as effective and economically feasible disinfestation agent in this sector. The pests of this product are difficult to control to US food hygiene standards -nil tolerance on inspection. There is an ongoing research program focusing on improving processing sanitation, IPM and pest control through a variety of possible fumigants and physical processes (Amoah et al., 2012, 2013; Abbar *et al,* 2013; Phillips et al., 2012 a; b). The results of investigations with various alternative fumigants and nonchemical treatments on the ham mite *Tyrophagus putrescentiae* have not been fully successful (Abbar et al. 2012; 2013; Zhao et al. 2012 a; b). Phosphine treatment using magnesium phosphide controlled the mites but let to inacceptable corrosion damage to exposed electronics (Phillips and Schilling, 2013). Research is ongoing and the change in hygiene and processing including the reconstruction of the houses seems to offer promissing pathways for future MB phase out.

Europe and USA have traditionally produced pork products preserved through processes such as dry-curing, smoking and salting. In the US, all ham would get salt. Salt is what keeps the product from rotting until it loses enough water to retard spoiling. Production requires an aging period for the hams to get the characteristic flavours. Under these aging conditions, the development of pest is a risk to take into consideration. Mold mites are the major pests affecting the final food product and food processing facilities. The main pest mite species is *Tyrophagus putrescentiae*. Other species present are *T. longior* and *T. casei*.

In Europe, for the control of mite infestations, the ham industry is no longer using MB since 2005 due to intensive sanitation and transition to alternatives. However, in the USA, the industry has not been able to entirely adopt available alternatives. Although IPM measures have reduced the number of times MB fumigation is needed, it has not fully eliminated the need for fumigation.

In order to prevent contamination, ham producers have to adopt high standards of sanitary procedures, the same as for other food and meat facilities and companies. In Europe, the old ham facilities nowadays have been transformed into modern meat processing factories. Specifically to avoid mite problems, the following procedures are widely followed in countries like Spain: high sanitation standards and intensive cleaning methods, fumigation of empty structures with PH_3 and use of other authorized pesticides, dipping the hams in oil and lard at 90°C including control of superficially occurring mites, strict control of the relative humidity (RH) during the process (initial 75 % to allow salt penetration and afterwards gradually decrease to 65%) and the control of moulds on and within the ham surface. Regarding the treatment with oil and lard at 90°C, this is applied early during the manufacturing process. This measure has both preventive and curative reasons. Exposure to high temperature kills mites that could be already present on the surface of the ham and lard fills crevices preventing the colonization of mites deep into the ham. Also, lard has another important advantage as it retards the speed of the drying process. Temperature and relative humidity determine the behaviour of mites (Sanchez-Ramos and Castañera, 2005). Controlling both parameters contribute to the prevention of this pest. Hams are maintained at low ambient RH conditions (50 – 60%) mainly during the last period of storage. This prevents the development mites that might have survived the hot oil treatment and avoids the colonization of newly infesting individuals from outside the store. Also, to maintain high hygiene standards inside the rooms, they are thoroughly cleaned when they are empty with use of pesticides within the facilities including the frames for later hanging new hams. These procedures are all together essential and must be followed by the industry.

A number of promising chemical alternatives have been identified. Among fumigants, the use of phosphine appears most promising with some modifications in application technique to avoid corrosion damage to exposed electronics (Phillips, 2013). In comparison, SF at ambient temperature of 25°C is at the regular dosage not effective in eliminating all the egg stages to the level that would effectively control pest mite populations. Recently, research is conducted to determine if its efficacy against mite eggs could be improved at higher fumigation temperatures of 35°C and longer exposure times of 48 h. Also, laboratory studies have been conducted to assess the potential of food-safe preservative coatings (Abbar *et al*., 2013; Zhao *et al*., 2012). These include sorbates and propylene glycol coatings on pieces of dry-cured hams that can repel and/or reduce reproduction.

The effective and feasible commercial use of carbon dioxide against pest mites in the ham industry has not yet been described. On the other hand it is known that exposure to gas mixtures of 50 vol.-% CO_2 in air at 25ºC for 12 days and 90 vol.-% CO_2 for 8 days, respecively, kill all developmental stages of pest mites (Riudavets *et al*., 2009)

6.6 General statements on alternative fumigants

6.6.1 Phosphine

Although phosphine is the fumigant of choice to replace MB in many postharvest treatments, some problems with its use need attention, particularly the possible development of resistance in the pests to be controlled. Very significant resistance has been reported in several species of SPP insects and options for overcoming it have been proposed (Asher, 2012; Bridgeman and Collins, 2012; Nayak, 2012; Newman *et al*., 2012ac; Phillips et al., 2012 c; Tumambing *et al*., 2012b). The fitness of phosphine resistant strains appears to be high so that resistance genes persist in the population in the absence of selection pressure (Daglish et al., 2014).

In the Philippines, several phosphine fumigations of grain, imported tobacco and seeds failed (Andres, 2013) however, phosphine is the only MB alternative available for use in these commodities. To date there are 4 brands of phosphine generating compounds and one cylinderized formulation that are registered and available.

Cylinderized phosphine is generally described (Tumambing *et al*., 2012 a). It has been successfully used for tobacco disinfestation in the Philippines (Andres, 2013) and is reported for use in Indonesia (Vidayanti *et al*., 2012).

Cryptolestes in Australia seems to have become resistant to phosphine to such a degree that it cannot be controlled with this gas at the registered dosage.

Phosphine is increasingly used for the disinfestations of fresh fruits against pest arthropods even at lower temperature of around 5°C (Horn, 2012).

Sulfuryl fluoride and phosphine in combination with heat are promising combinations for pest control in flourmills (Fields, 2012).

A new type of generator (Malushkov *et al*., 2012), which produces the phosphine on site (Ryan and Shore, 2012), an automatic fumigation system (Naik and Shroff, 2012b), a new recirculation system (Zakladnoy et al., 2012) and thermosiphon pipes for better gas distribution (Newman et al., 2012a) have been described.

Older reports confirm the occurrence of phosphine resistant pest insects in stored grain. To address phosphine resistance, fumigators opt to increase dosage and prolong exposure. Target concentration of phospine at 10 days exposure at 30 °C is > 300 ppm. In extreme cases, consecutive fumigation of 10-15 days exposure is resorted to.

6.6.2 Sulfuryl fluoride

Buckley and Thoms (2012) have presented a comprehensive overview on the worldwide use of SF for control of various pests in various products and situations. Noppe et al. (2012) mention the treatment of cocoa beans in the EU and Sen et al. (2012) that of dried apricots, raisins and hazelnuts. Walse (2009) reported on SF against eggs of stored product pests on dried fruit. China has three factories producing SF for local use and export. The fumigant is used for the treatment of grain, cotton and timber. The substance is also used for disinfestation of museums in the USA. SF is in use for disinfestations of museums (structures) against insect pests in Japan (JIIDCP, 2014). SF is now intensely used for disinfestation of bulk grain in Australia, also for resistance management of phosphine (Thoms *et al*., 2012).

Laboratory and field data have been presented for the control of all stages of species of pest insects (Flingelli *et al*., 2014; Lawrence et al., 2012) as well as a new detection device (Naik and Shroff, 2012a).

Sulfuryl fluoride (SF) was registered for stored product protection in 2004 as ProFume® by the DowAgroscience Company (Buckley and Drinkall, 2010). This company undertook a large effort to investigate the necessary CTPs and dosages for control of many pest insects and mites that can infest stored food products and other material. SF has also been registered for control of termites (Meikle et al., 1963) and wood pest insects (Williams and Sprenkel, 1990) under the name Vikane®.. SF has been used for termite control for about 50 years (Kenaga, 1957). SF has been independently developed in China as a grain fumigant and methyl bromide alternative and is produced in that country as previously stated.

From the very first introduction of this compound for pest control in the US it was obvious that eggs of arthropods were the most tolerant developmental stage and that they could not be killed for many species at dosage rates that eliminated the adult stage. Also a strong dependency of the lethal dosages on temperature became soon very evident. This can clearly also be seen from Table 1 when comparing the CTPs for eggs of one species at different given temperatures with higher temperatures leading to lower CTPs for control. Explanations for these dependencies have been suggested by Meikle *et al*. (1963) and Outram (1967a; 1967b). Uptake of SF by eggs compared to other developing stages and adults is much less pronounced and seems to be linked to the properties of the egg shell membranes. On the other hand, the lethal effect seems to be linked to physiological processes that are reduced at lower temperatures. The registration of SF for fumigating food processing structures and commodities by DowAgroscience was accompanied by the introduction of a proprietary computer program (Fumiguide®) to optimise SF fumigation efficiency under particular situations. Inputs to the Fumiguide include many scientific and technical factors that describe an effective fumigation, including species, stage, temperature, exposure period and loss rate of SF due to expected leaks on the base of a gas tightness test, wind speed, and commodity to be treated. All this information has to be introduced by the fumigator to obtain the necessary amount of SF that should be applied in a particular fumigation. In certain cases the guide even gives the top up quantity of additional gas required to achieve the set ct-product, based on gas concentration measurements and identified losses of gas during the treatment. In some countries the Fumiguide is not publicly available, but linked to licencing of SF use by the registrant.

During many fumigations performed in the US after 2004, it was found by practitioners and scientists that mostly all the pests were controlled, provided the recommendations of the Fumiguide were followed. The temperature range of the current Fumiguide is limited to temperatures above 20°C and below 40°C.

One specific information need of Parties concerns the need to understand the function and improve the efficacy of sulfuryl fluoride. Fumigation with SF is one of the pest control methods adopted by some parties as the principal alternative to methyl bromide in some major postharvest and structural uses. The lack of full effectiveness of SF against eggs of pests is mentioned in several critical use nominations. To assist in understanding, and hopefully resolving, this problem, MBTOC prepared a Special Review, which can be found in the TEAP Progress Report of May 2011 (TEAP, 2011). The report included recommendations on SF treatment parameters by pest species for the consideration of Parties and their applicants.. Parties, MBTOC, CUN applicants and researchers continue to note inconsistencies in the observed efficacy of SF in practice. This is of concern as fumigation with SF is one of the pest control adopted by some parties as the principal alternative to methyl bromide in some major postharvest and structural uses. The lack of full effectiveness of SF against eggs of pests is mentioned in several critical use nominations. To assist in understanding, and hopefully resolving, this problem, MBTOC SC prepared a Special Review, given below (section 4.6.2.1) of reported laboratory studies on SF in controlling eggs of stored product insect pests. This review provided a basis for analysis of the lack of full control of pests by SF in some commercial fumigation.

As a result of its review, MBTOC concludes that:

- the target dosage rate of SF, typically a ct-product of 1500 g h m-3 over 24h at 26°C, is insufficient to fully control eggs of some common species of stored product insect pest
- many common pests will be fully controlled (all developmental stages including eggs) to commercial levels under these conditions.

It is important to achieve a high degree of kill of infestations, including the egg stage, under situations where resistance development may be a risk.

MBTOC noted that the actual ct-product experienced by pests, including their eggs, may be less than the free space ct-product under conditions where there are significant barriers to gas distribution, such as packaging materials.

The review and analysis reported here merits further examination and testing by researchers and refinement by pest control fumigators, but at this point, we believe the information could act as a guide to improving the efficacy of SF fumigations as methyl bromide replacements.

6.6.2.1. Extracts of the special review on achieving control of pests including their eggs by sulfuryl fluoride (MBTOC, 2011b)

Fumigations that target only 95% efficacy in killing pest eggs can quickly result in severe reemergence of infestation and can eventually result in pest resistance to the fumigant, after repeated fumigations. Where there is risk of resistance development (e.g. with repeated treatments of infested premises) fumigations should be conducted to achieve a very high level of kill (>99%) of all pest life stages, including eggs. Because of varied mortality responses (including by the tolerant egg stage) to SF, identification of the pests of concern before the fumigation is required to select treatment parameters necessary to achieve full efficacy.

This predermination of the occurring pest species is in accordance to the requirements of the computer program Fumiguide that is used by fumigators applying SF from Dow Agrosciences. Knowledge gained from the pest identification, when coupled with the data shown in the review tables in the Appendix, can be used to determine the treatment parameters necessary for egg mortality. Crucial factors for limiting egg tolerance are temperature and length of exposure, and level of concentration, which operate differently on different species. Other important factors affecting response to SF include the developmental period of the embryo, the structure of the egg shell and other compounds of the egg.

Achieving an effective treatment may require a combination of concentration and time and elevated temperature, which is not currently found elsewhere.

The dosage/mortality values determined in laboratory studies may be used as a basis of commercial dosage recommendations, with allowance for the various inefficiencies and deviations from ideal systems that occur in practice. Reichmuth (2010b) proposed a factor of three times for conversion of laboratory-derived values to commercial applications.

Some researchers and food processing companies have reported inadequate control of pest eggs with SF and difficulties understanding the research in that field. In many situations, pest control methods, used as a single control measure, are not considered to be adequately effective if they do not control the eggs as the facility or commodity will become noticeably infested again from survivors within very few weeks. Some commercial recommendations for the use of SF in food processing structures and commodities target a 95% kill of pests. It is the opinion of MBTOC members that fumigations with less than 99% efficacy of killing pest eggs are undesirable because of possible selection for resistance under situations where the SF fumigant is the sole control measure used and repeated exposures are likely.

The reason for this is that survivors of such repeated unsuccessful fumigations will eventually become resistant to the fumigant -- and the fumigant will not longer be useful, including as a methyl bromide replacement. On the other hand, if other subsequent, additional control measures including IPM processes (e.g. a second fumigation, cooling, heating or further processing) were to be used in addition to the SF fumigation, and if a resulting additive kill-effect could be validated to 99%, then a 95% kill of all stages, with 'complete' kill of adults, may be sufficient both technically and commercially. Additionally, increasing the temperature and/or duration of the fumigation for a particular dosage will also help to increase effectiveness of the fumigation in a gas tight structure.

However, in the absence of MB, it is likely that SF will be used repeatedly as a postharvest fumigant in many applications without achieving full control, thus setting the conditions for pest resistance (i.e., if the treatment(s) are not effective to >99%). Since eggs tend to be much more tolerant than other developmental stages to SF, it is critical that the conditions leading to >99% mortality of eggs are understood if control to >99% efficacy is to be achieved.

Given the problems outlined above, several MBTOC members, led by Prof. Dr. Christoph Reichmuth (Germany) collated available data on the fumigation of eggs of stored product insects and especially those occurring in rice and flourmills, the situations of particular concern where SF is a potential or actual methyl bromide replacement.

In the review only those data points, which showed efficacy of at least 99% are included. Quarantine treatments may require effectiveness much greater than 99% mortality, and so were excluded from the analysis.

Table 6-1 summarises published mortality data and lethal responses of eggs of 28 economically important insects and mites following fumigation with sulfuryl fluoride at 20°C. data for other temperatures can be found in MBTOC, 2011b. Additional information on the pests can be obtained from Reichmuth (2007ab) and in the cited references. This table provides Parties access to research data on specific pest species where control of pest eggs was >99%. Some authors calculated LD95 and spoke of "complete control", whereas others presented CTPs that were lethal to all eggs in the test (no survivors or no development to adults).

Figure 6-1 presents a bar graph of the reported minimum and maximum ct-products required for 99% efficacy of control of eggs of various pest species.

Table 6-2 sorts pest species into groups that are probably, possibly or unlikely to be controlled at 1,500 g h m^{-3} at at 26.7°C (80°F) and 24 h exposure. This ct-product is the maximum rate that is allowed under the registration of SF as a pesticide ('label' rate) for control of all developmental stages of stored product pest, such as specified in the 'Fumiguide', a proprietary guide to the use of SF as a postharvest and structural fumigant. This rate is targeted at only 95% mortality.

As with other fumigants, there is a wide range of sensitivity to SF fumigant with different pest species and developmental stage with some insect species tolerating much higher exposures than others. The eggs themselves develop through different stages that differ markedly in uptake of gas and ct-products that can give high mortality (see Table 4-2 where response of eggs with different age are summarised for 20°C as exposure temperaure). The different stages have been prepared in the laboratory by waiting various hours after egg laying before introducing them into a test fumigation. The development of the embryo differs in these eggs of different ages and also the structure of the egg shell and other components of the egg. The kinetics of these processes are strongly dependent on temperature.

Crucial factors for limiting egg tolerance are temperature and length of exposure, which operate obviously differently on different species. The table shows that even for tolerant species such as *Ahasverus advena* at 20°C, length of exposure is the key to reducing the dosage levels required for control to the practically feasible level of 1500 g h m^{-3}. With this species, the CTP depends strongly on exposure time and not so strongly on concentration of SF during the treatment. For *A. obtectus* and *A. advena* with eggs starting to hatch a week after oviposition at 20°C, increasing the exposure to four or seven days greatly affects tolerance at this temperature. The length of the phase of high tolerance in the egg stage (varying between species so some are more tolerant than others) is a fixed proportion of the total egg development time and so is temperature dependent. Development continues during exposure to SF until a susceptible stage is reached. If gas is still present, the egg succumbs.

For use of SF in control of insects that occur in rice storage in Australia, e.g. *Tribolium castaneum* and *Sitophilus oryzae*, necessary basic information for the dosage can be derived from Table 6-2. Unfortunately, *T. castaneum* belongs to the very few species that eggs are pronouncedly more tolerant than eggs of most other species. The maximum ct-product that is recommended by the Fumiguide® (1500 g h m^3) does not guarantee the complete control of all eggs present, at least not at 20°C. Reichmuth (2007b, 2010a, 2010b) has tried to demonstrate the limitations of not killing all the present eggs of a pest species in the context of the speed of rebound time of infestation after a fumigation. The speed of rebound depends on temperature. Typically common stored product pests lay 40 to 200 eggs per female. With a 99% kill of adult females, the remaining female can lay eggs that can then develop into the same level of infestation as before the treatment. Generation times can be a few weeks or months depending on species and temperature. A goal of, for instance, control of only 95% is totally insufficient within the food industry where zero tolerance of insects in food is the rule. It is a weak argument to say that new infestation will occur the very moment after the mill or other object of fumigation has been aerated and reopened. The client and government inspectors regulating the mill or food-processing facility will expect that there will be actually or nearly no surviving pest insects and stages following a SF fumigation.

Schaub (2010) dealt with the financial and economic aspects of fumigation in stored product protection. It is known that in practice, gas leaks, temperature sinks of 10°C, residual flour of 10 cm thick layers may occur. The avoidance of all these factors that can jeopardize the success of a fumigation is nearly impossible.

A fumigation plan which targets or results in less that 99% control is bad fumigation practice and may result in survivors that are more tolerant than the regular field strains. Campbell et al. (2010) dealt with the question of rebound of pest populations, considering field conditions. Harzer et al. (2010b) presented more detailed information on the field fumigations, which led to the results in Harzer et al. (2010a). Ciesla and Ducom (2009), subsequently gave also more detailed information (Ciesla and Ducom, 2010).

Reichmuth and Klementz (2008ab) compared the selection of the appropriate dosage for practical fumigation for methyl bromide and sulfuryl fluoride treatments. It was accepted as a reasonable, conservative approach to multiply the lethal dosage determined in the laboratory with a factor of about three to obtain the practical dosage. With MB, for example, 20 g m^{-3} is an accepted concentration for space fumigations, even though in the lab a concentration of only 5 g m^{-3} results in complete control for most species and stages over the same exposure time. However, with SF, as shown in Table 6-2, the theoretical values from the laboratory were converted into the recommended commercial dosing in the field mostly without giving some tolerance for practical imperfections typically encountered, as discussed. Reichmuth (2010b) proposed a factor of three for this conversion.

Another possibility to overcome the increased tolerance of the egg stage in using SF for insect pest control is the combination with other fumigants (Muhareb, 2009). Xiaoping *et al*. (2008), Ling *et al*. (2008) and Guogang *et al*. (2008) proposed the combination with carbon dioxide, whereas Reichmuth and Klementz (2008a) showed data on the very effective combination of SF with hydrogen cyanide (HCN). Of course, the combined use of heat or elevated temperature and SF offer an opportunity to economise on use of SF and still kill all eggs and other stages present. The use of supplemental heat to achieve sufficient egg kill in SF fumigations has been recommended by MBTOC since its 2008 Progress Report. This technique may also be applicable with packed food.

Walse (pers. comm.) confirmed the range of the necessary ct products to control egg stages (especially the one day old eggs) of the dried fruit beetle with about 4500 g h m^{-3} being necessary even at 25°C. According to Walse (pers. comm.) his unpublished experimental results showed that the ct products for LD50 he observed are slightly higher than those described by Flingelli *et al*. (2012, 2014) especially at the highest experimental temperature. Athanassiou *et al.,* (2012) investigated the efficacy against stored product psocids.

Some infestable stored foodstuffs are typically fumigated after packaging. There is an interrelationship between the permeability of the packaging and the efficacy of SF fumigation.

Some authors (Osbrink *et al*., 1988; Scheffrahn *et al*., 1990) described the permeation of SF through different plastic membranes. Scheffrahn et al. (1990) describes most of what is needed to know on pack permeability to SF and its low rate of permeation compared with methyl bromide through plastic films. On the basis of data from Scheffrahn *et al.* (1990), a 24 hour exposure to SF is unlikely to give lethal (ovicidal) concentrations within an intact laminate bag of rice. This conclusion is based on the likely diffusion and permeation of SF through plastic laminates that are used to package possibly infested processed rice in Australia. The influence of the pinholes is undefined and probably quite variable. It may be useful for Australia to consider the quoted references. Furthermore, it should now be possible to determine the likely SF and fluorine ion (F-) residues that may be formed in the course of an effective fumigation with SF.

TABLE 6-1. CT-PRODUCTS FOR SULFURYL FLUORIDE GIVING >99% MORTALITY OF EGGS OF VARIOUS STORED PRODUCT PESTS, GIVEN IN PUBLISHED LABORATORY AND FIELD TEST RESULTS AT 20°C AND DIFFERENT EXPOSURE PERIODS

Species and strain Laboratory tests	Egg age in days	Ct-product For >99% mortality in g h m-3	Exposure period in days	SF con-centration in g m-3	Reference
Ahasverus advena	All	4656	1.67		Bell (2006)
Ahasverus advena	All	3072	4		Bell (2006)
Ahasverus advena	All	1966	7		Bell (2006)
Acanthoscelides obtectus	All	1070	1		Bell (2006)
Acanthoscelides obtectus	All	605	4		Bell (2006)
Ahasverus advena	All	4656	1.67		Bell (2006)
Ahasverus advena	All	3072	4		Bell (2006)
Ahasverus advena	All	1966	7		Bell (2006)
Acanth. obtectus	All	1070	1		Bell (2006)
Acanth. obtectus	All	605	4		Bell (2006)
Crypt. ferrugineus (PH3 res)	all st	720	1	30	Baltaci et al. (2008)
Crypt. ferrugineus (PH3 res)	all st	720	3	10	Baltaci et al. (2008)
Crypt. ferrugineus (PH3 res)	all st	960	2	20	Baltaci et al. (2008)
Carpophilus hemipterus	2	2400	1	100	Karakoyun and Emekci (2010)
Ephestia cautella	1	1440	1	60	Akan and Ferizli (2010)
Ephestia cautella	2	3360	1	140	Akan and Ferizli (2010)
Ephestia cautella	3	3360	1	140	Akan and Ferizli (2010)
Ephestia elutella	1-4	683 (99)	0.75-2	11.6	Baltaci et al. (2009)
Ephestia elutella	1-4	624 (99)	0.75-2	21.3	Baltaci et al. (2009)
Ephestia kuehniella		1680	2	35	Drinkall et al. (1996)
Ephestia kuehniella		2520	3	35	Drinkall et al. (1996)
Ephestia kuehniella	All	1688	2	35	Klementz et al. (2008)
Ephestia kuehniella	All	1688	2	35	Klementz et al. (2008)
Ephestia kuehniella	All	842	3	11.7	Klementz et al. (2008)
Ephestia kuehniella	1	480	1		Reichmuth et al. (1999)
Ephestia kuehniella	1	960	2		Reichmuth et al. (1999)
Ephestia kuehniella	1	720	3		Reichmuth et al. (1999)

Species and strain Laboratory tests	Egg age in days	Ct-product For >99% mortality in g h m-3	Exposure period in days	SF concentration in g m-3	Reference
Ephestia kuehniella	2	480	1		Reichmuth et al. (1999)
Ephestia kuehniella	2	960	2		Reichmuth et al. (1999)
Ephestia kuehniella	2	720	3		Reichmuth et al. (1999)
Ephestia kuehniella	3	1440	2		Reichmuth et al. (1999)
Ephestia kuehniella	3	1440	3		Reichmuth et al. (1999)
Ephestia kuehniella	4	1440	2		Reichmuth et al. (1999)
Ephestia kuehniella	4	720	3		Reichmuth et al. (1999)
Ephestia kuehniella	All	1860-2255 (99.4)	1.5-2		Reichmuth et al. (2003)
Oryzaephilus mercator	all st	>720	1	>30	Baltaci et al. (2008)
Oryzaephilus mercator	all st	1440	2	30	Baltaci et al. (2008)
Oryzaephilus mercator	all st	720	3	10	Baltaci et al. (2008)
Oryzaephilus surinamensis		636	1	26.5	Drinkall et al. (1996)
Oryzaephilus surinamensis		1272	2	26.5	Drinkall et al. (1996)
Oryzaephilus surinamensis		958	3	13.3	Drinkall et al. (1996)
Oryzaephilus surinamensis	All	319	1	13.3	Klementz et al. (2008)
Oryzaephilus surinamensis	All	638	2	13.3	Klementz et al. (2008)
Oryzaephilus surinamensis	All	958	3	13.3	Klementz et al. (2008)
Oryzaephilus surinamensis	All	1860-2255	1.5-2		Reichmuth et al. (2003)
Plodia interpunctella		564	1	23.5	Drinkall et al. (1996)
Plodia interpunctella		562	2	11.7	Drinkall et al. (1996)
Plodia interpunctella		842	3	11.7	Drinkall et al. (1996)
Plodia interpunctella	All	281	1	11.7	Klementz et al. (2008)
Plodia interpunctella	All	562	2	11.7	Klementz et al. (2008)
Plodia interpunctella	All	842	3	11.7	Klementz et al. (2008)
Rhyzopertha dominica	All	912	0.83		Bell (2006)
Rhyzopertha dominica	All	762	2.42		Bell (2006)
Rhyzopertha dominica	All	912	5		Bell (2006)
Sitophilus granarius		840	1	35	Drinkall et al. (1996)
Sitophilus granarius		1680	2	35	Drinkall et al. (1996)
Sitophilus granarius		1339	3	19	Drinkall et al. (1996)

Species and strain Laboratory tests	Egg age in days	Ct-product For >99% mortality in g h m-3	Exposure period in days	SF concentration in g m-3	Reference
Sitophilus granarius	All	840	1	35	Klementz et al. (2008)
Sitophilus granarius	All	1680	2	35	Klementz et al. (2008)
Sitophilus granarius	All	1339	3	18.6	Klementz et al. (2008)
Stegobium paniceum	All	437	1	18.2	Drinkall et al. (1996)
Stegobium paniceum	All	874	2	18.2	Drinkall et al. (1996)
Stegobium paniceum	All	1310	3	18.2	Drinkall et al. (1996)
Tribolium castaneum	All	960 + HCN (100)	2	20 + 1.5 HCN	Reichmuth and Klementz (2008a)
Tribolium castaneum	All	72 (HCN) (85)	2	1.5 HCN	Reichmuth and Klementz (2008a)
Tribolium confusum		319	1	13.3	Drinkall et al. (1996)
Tribolium confusum		638	2	13.3	Drinkall et al. (1996)
Tribolium confusum		958	3	13.3	Drinkall et al. (1996)
Trogoderma inclusum		437	1	18.2 18.2	Drinkall et al. (1996)
Trogoderma inclusum		562	2	11.7	Drinkall et al. (1996)
Trogoderma inclusum		1310	3	18.2	Drinkall et al. (1996)
Tenebrio molitor	All	1860-2255 (99.5)	1.5-2		Reichmuth et al. (2003)
Trogoderma versicolor	All	437	1	18.2	Klementz et al. (2008)
Trogoderma versicolor	All	562	2	11.7	Klementz et al. (2008)
Trogoderma versicolor	All	1310	3	18.2	Klementz et al. (2008)
Sitophilus zeamais	All	92 + 441 (CO_2)	0.25	15.38+ 73.58 (CO_2)	Guogang et al. (2008)

Abbreviations: All = all egg ages; all st = all developing stages

FIGURE 6-1. LOWEST AND HIGHEST REPORTED CT-PRODUCTS IN THE LITERATURE FOR THE COMPLETE CONTROL OF EGGS OF THE VARIOUS PEST INSECTS (FROM MBTOC 2011B)

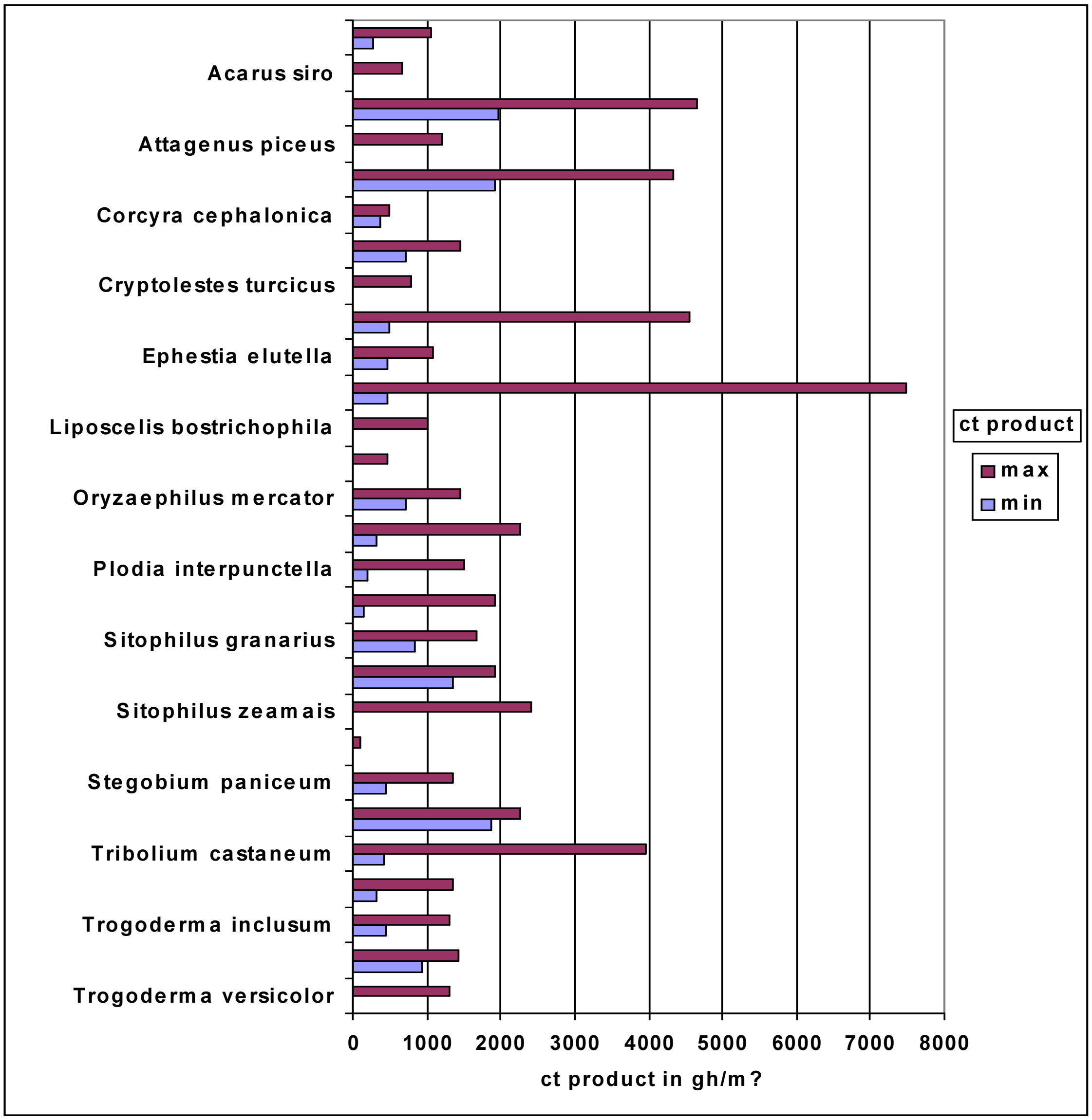


TABLE 6-2. GROUPING OF PEST SPECIES BY PROBABLE, POSSIBLE AND UNLIKE CONTROL OF EGGS BY SULFURYL FLUORIDE AT 1500 G H M^{-3} AT 26.7°C

Species: common name	Species: scientific name	ct-product in g h m-3 giving 99% mortality	Reference
PROBABLE EGG CONTROL AT 1500 g h m-3 and 26.7°C			
Rust-red grain beetle	*Cryptolestes ferrugineus*	~720	Baltaci et. al (2008)
Merchant grain beetle	*Oryzaephilus mercator*	~720	Baltaci et. al (2008)
Warehouse moth	*Ephestia elutella*	~500	Baltaci et. al (2006)
Rice moth	*Corcyra cephalonica*	~500	Barakat et al (2009)
Psocid	*Liposcelis bostrichophila*	1000	Bell et al (2003)
Grain beetle	*Cryptolestes turcicus*	780	Bell et al (2003)
Flour mite	*Acarus siro*	700	Bell et al (2003)
Warehouse beetle	*Trogoderma variabile*	~1000	Bell et al (1999)
POSSIBLE EGG CONTROL AT 1500 g h m-3 and 26.7°C			
Mediterranean flour moth	*Ephestia kuehniella*	500-1300	Baltaci et al (2006); Drinkall et al. (2003); Ducom et al. (2003); Reichmuth and Klementz (2008a)
Indian meal moth	*Plodia interpunctella*	1000-1300	Drinkall et al (2003) ; Ducom et al. (2003)
Confused flour beetle	*Tribolium confusum*	600-1300	Bell et al. (1999); Ciesla and Ducom (2009); Drinkall et al. (2003)
Rice weevil	*Sitophilus oryzae*	1300	Drinkall et al. (2003)
Lesser grain borer	*Rhyzopertha dominica*	1300	Drinkall et al. (2003)
Drugstore beetle	*Stegobium paniceum*	1300	Drinkall et al. (2003)
UNLIKELY EGG CONTROL AT 1500 g h m-3 and 26.7°C			
Almond moth	*Ephestia cautella*	1400	Akan and Ferizli (2010)
Granary weevil	*Sitophilus granaries*	1000-1500	Ducon et al (2003); Reichmuth and Klementz (2008a)
Red flour beetle	*Tribolium castaneum*	1500-1850	Drinkall et al (2003); Ducom et al. (2003); Reichmuth and Klementz (2008a)
Dried fruit beetle	*Carpophilus hemipterus*	~4500	Karakoyun and Emekei (2010)

6.6.3 Propylene oxide

In Japan, propylene oxide is used for treatment of museums to control pest insect and microbial diseases (JIIDCP, 2014). Propylene oxide is used against moulds in the US. The efficacy of propylene oxide in combination with carbon dioxide against eggs of stored product pests was demonstrated (Gautam et al., 2013).

6.6.4 Ethyl formate

VAPORMATE, a mixture of ethyl formate and carbon dioxide, is used in Australia, New Zealand and South Korea to disinfest stored product grain; products like cereal and legume grain (Glassey, personal communication), is further investigated for treatment of various stored products (Finkelman et al., 2012) and against book lice (Wang and Hui, 2012). Ethyl formate is proposed and used for disinfestations of fresh fruit (Agarwal *et al*., 2012), grain (Dojchinov et al., 2009; Ren and Mahon, 2006; Xin *et al*., 2008) and dates (Finkelman *et al*., 2010), beans (Ren and Mahon, 2006) and sorghum (Ren and Mahon, 2006). Thalavaisundaram and Roynon (2012) have described the penetration of the gas into wrapped card board boxes.

6.6.5 Controlled atmospheres

Adoption of Controlled Atmospheres (CA) and Modified Atmospheres (MA) as a means to control pests in food commodities and spaces where food is being stored continues to increase. CA and MA treatments offer large commercial and small packing houses, even farmers, effective postharvest pest control options useful for most durable commodities (and even non-food commodities such as museum and historical artefacts), under a very wide range of circumstances, without using chemical fumigants. For these reasons, the technique has spread widely, quickly and there are several companies offering equipment, service, products and assistance. The CA treatment is based on creating a low-oxygen environment within a structure (new or existing) with airflow control [airtight, gastight]. This technology provides a low-oxygen environment with oxygen levels of less than 1% causing death of pests.

There is an increasing introduction of inert gases with low residual oxygen content (mainly nitrogen and carbon dioxide, including vacuum) into the field of pest control in stored product and material protection (Adler *et al.,*, 2012; Aksoy *et al*., 2012; Andres, 2013; Aulicky *et al*., 2012; Banks, 2012; Biebl and Reichmuth, 2013; Calderón and Barkai-Golan, 1990; Cavalho et al., 2012; Corinth and Reichmuth, 2013; De Bruin *et al*., 2012; Huivi *et al*., 2012; Kucerova *et al*., 2012; Navarro, 2012; Navarro *et al*., 2012; Recichmuth *et al,* 1993; Ren *et al*., 2012; Sabio *et al*., 2012; Sen *et al*., 2012b; Son *et al*., 2012; Sotirouadas, 2012; Tao *et al*., 2012; Wong *et al*., 2012; Zeng *et al*., 2012).

Some facilities for the application of carbon dioxide and nitrogen are being erected in Indonesia and the Philippines (operational by Mai 2014) for control of insects in stored tobacco (cut fillers) (Gonzalez, pers. comm.). In the Philippines, high value stored products (cocoa powder, cut feeders) are treated with nitrogen from cylinders (less than 2 vol.-% oxygen) under tarpaulins, and seeds under hermetic conditions (Tado and Gummert, 2012).

In Albany, Western Australia, large steel bins and gas tight concrete silos have recently been erected for use of nitrogen with very low residual oxygen content of less than 1 vol.-% to treat stored grain prior to export against insects (Banks, personal communication).

Eleven new CA commercial projects were opened in 2011 and the first months of 2012 in the countries Cyprus, France, Greece, Ivory Coast, Singapore, Switzerland, United States and Vietnam by the Dutch company ECO_2. Other companies such as Linde (2013), Messer, and Air Liquide for example, also use controlled atmosphere technologies for pest control. Different commodities and related pest insects are controlled in either gastight constructed treatment rooms or prepared silo complexes by applying Controlled Atmosphere.

During each CA treatment, the following parameters are controlled and monitored to ensure an adequate treatment:

- The temperature within the treatment environment, including inlet temperature, air temperature, product temperature. The required product temperature needs to be reached throughout the products being treated.
- The required level of oxygen needs to be maintained within the treatment environment during the entire treatment process.
- The duration of the treatment is based on the results of research on the response of target pests to CA.
- Circulation within the chambers needs to be managed to achieve an evenly distributed level of CA and temperature within the treatment environment during the treatment process.

Each insect species and its the various life stages has its own optimum conditions to live and consequently its own parameters to be successfully eliminated.

Another application related to insect control is the use of CA or MA, for instance by GrainPro and other companies, offering CA or MA storage bags or ‘bubbles’ in a wide range of sizes (1 kg – 1000 kg). This application is based on insect control and simultaneous quality preservation during storage of packed commodities such as nuts, coffee, cocoa beans, rice and seeds. Commodities, stored in CA/MA bags are packed under low-oxygen conditions ensuring no discoloration and ageing along with insect control and prevention of insect re-infestation.

A study by Pons *et al*. (2010) established the efficacy of using CO_2 in big bags and containers to prevent pests’ development. Four trials were conducted with gastight big bags (900 x 900 x 1000 or 1600 cm). Two of these trials were conducted with polished rice and samples of *Sitophilus oryzae*, one trial with chamomile infested with *Lasioderma serricorne* and one trial with cocoa and samples of *Tribolium confusum* and *Ephestia kuehniella*. Initial contents of CO_2 were higher than 75%, which decreased depending on exposure time (13 to 90 d) and food product. In all four trials the insects presentin the infested samples were controlled with the MA. An additional trial was conducted in a 9 m container containing dried herbs in boxes, big bags and other packaging formats. Twelve infested samples of *L. serricorne* and *Plodia interpunctella* were distributed uniformly at the bottom and top of the container. A concentration between 70% and 15% CO2 was maintained for an exposure time of 18 d. In spite of the decrease in CO_2 content, the treatment was also effective to control all insects present in the samples. The results confirmed that CO_2 could be applied to food products during the storage in big bags and containers to control the occurrence of pests. The authors concluded that modified atmospheres (MA) based on high carbon dioxide (CO_2) offer an alternative to synthetic chemical fumigation for insect pest control in food commodities during storage and shipment processes (Pons *et al*., 2010).

The various forms of hermetic bags are an excellent smallholder innovation with Crop Storage bags (PICS), a triple-lined 80 kilogram plastic bag being one of these. There have been many attempts to get them into routine use. Hermetic bags may deserve economic interest but the initial investment of two US$ eventually loses out compared with the polypropylene bags at fifty cents, despite multiple use and superior performance. Another problem is that for instance some pests like the Larger Grain Borer *Prostephanus truncatus*, can bore out of the bags quicker than the hermetic process kills them. So the integrity of the bag is compromised. Moisture within the bag may also lead to growth of moulds. In general terms, the use of hermetic storage with gas tight plastic bags may be applicable in some situations in Art 5 countries, but mostly in situations where MB was never used or considered for use.

A strong advantage of using CA/MA is that re-infestation after treatment is not possible (as long as the bag or bubble maintains its integrity) and goods are protected against external influences. These bags are convenient and applicable for many of the pest control needs faced by A5 Parties.

6.6.6 Methyl iodide

Although registration for MI has been suspended by its manufacturer in many countries, it is being used in Japan to treat fresh chestnuts since autumn 2014. Arysta Lifesciences Corporation (Japan) announced in 2013 that its MI business was being transferred to Itzusuja Chemical Industries Japan, which initiated promotion for practical use in chestnuts in late 2014 (Arysta, 2013).

6.6.7 MITC and CO_2

This mixture (MITC 30%) is presently registered and used in Japan for the treatment of logs and branches against forest insect pests (FAMIC, 2014).

6.6.8. Ozone

Ozone is frequently mentioned as an alternative to MB for disinfestation of stored products (Hasan *et al*., 2012). Athanassiou *et al*. (2014) describe their results to control *Plodia interpunctella, Tribolium confusum*, *Cryptolestes ferrugineus* and *Oryzaephilus surinamensis* with ozone. All species were tested at three different concentrations, 55, 115 and 210 ppm, for 2, 4, 6 and 8 h, respectively. Generally, at the two highest dose rates, all mobile stages were dead after 6 h of exposure, with *T. confusum* adults being the most tolerant. On the other hand, pupae and especially eggs were less susceptible to ozone, given that mortality did not exceed 85 and 55% for pupae and eggs, respectively, regardless of the dose and the exposure interval.

6.6.9. Nitric oxide (NO)

NO has been shown to be an effective fumigant against various pests of perishable and durable foodstuffs at low temperatures (2°C) under anaerobic conditions, with potential to replace MB fumigation in some applications (Liu, 2013a). MB fumigation of cooled perishables often requires heating the treated commodity to 10°C or more to be effective, with loss of shelf life and quality.

6.6.10. Chlorine dioxide gas

ClO_2 has been successfully tested against all stages of *Tribolium confusum* and *T. castaneum* (Channaiah *et al*., 2012).

6.6.11. Ethylene dinitrile (EDN)

EDN is described as fumigant for logs and timber (Park *et al.*, 2012).

6.6.12. Carbonyl sulfide

COS, developed in Australia, is still under investigation as an appropriate fumigant for control of pest organisms in stored product protection (Liu *et al*., 2012).

6.6.13. Other fumigants

Disinfestations of artifacts, monuments and logs with fumigants other than MB (methyl iodide, sulfuryl fluoride, cypermethrin, especially against the six-toothed bark beetle *Ips sexdentatus* has been reported (Ciesla *et al*., 2012; Floréal *et al*., 2012).

6.7. Other (non-fumigant) alternatives

6.7.1. Irradiation

The use of irradiation as a phytosanitary treatment has increased and in 2013 nearly 13,000 tonnes of irradiated fruit were marketed in the US, a dramatic 6,500% increase since 2007 (Jeffers, 2014). These products include purple sweet potatoes from Hawaii, mangoes from India; guava, mangoes and papayas from Mexico; grapes from South Africa; lychees, mangosteen and rambutan from Thailand; and Dragon fruit from Vietnam. Additionally, about 175 million lbs of spices are irradiated each year in the US as a treatment against microbial contamination.

6.7.2. Biological control

In Europe - especially in Germany - and in the US, parasitic wasps and predators now comprise a significant parts of pest management programs for facilities and stored products e.g. empty factory rooms, and grain and spices, especially in the organic sector (Schöller *et al*., 1997; Schöller, 1998, 2010, 2013; Reichmuth, 2013; Steidle and Niedermayer, 2013,).

6.7.3. Diatomaceous earth

Protectants like diatomaceous earths or other contact insecticides still serve to disinfest grain from pest insects (Korunic *et al*., 2012). Ulrichs and Mewis have investigated the potential of nanostructured silica for arthropod pests (2013). Ciesla and Guéry (2014) report on the combined use of diatomaceous earth and heat against *Sitophilus oryzae*.

6.7.4 Optimized processing and storage design

In grain storage in the Philippines, (mostly rice), improved processing equipment and techniques are implemented (dryers, drying technique, separating machines) to protect grain against pest insects without use of chemical disinfectants (Gonzalez, pers comm).

6.7.5. Heat

Heat has been mentioned again for the treatment of food processing facilities (Subramaniam *et al*., 2012) as well as cold to control beetles and moths (Adler and Reichmuth, 2013). Navarro and Finkelmann (2004) and Navarro *et al,* 2014 report on heat susceptibility of Carpophilus hemipterus eggs and larvae, an insect that are difficult to control and are/were target of MB fumigations. The use of a fluidized bed of wheat as a disinfestation method to control preimmature stages of Sitophilus spp. was again investigated under laboratory conditions (Fleurat-Lessard and Fuzeau, 2014). The lethal temperature ranged from about 1 minute at 60°C to 7s at 150°C. The experiments included also the determination of the relevant food technological properties of the treated wheat. Vacquer *et al*. (2014) report on the first successful heat disinfestation in a large wheat mill in France with electrical heaters from the Hofmeir company.

6.7.6. Essential oils and other plant extracts

Plenty of references describe results of mostly laboratory experiments with extracts of various plants against various stored product pest insects (JSPR and other sources) also as alternatives for the use of MB (Abdelgaleil *et al*., 2012; Ahnadi and Moharrmipour, 2012; Akrami and Moharrmipour, 2012; Jemâa *et al*, 2012; 2013; Haouel *et al*., 2012; Khemira *et al*., 2012; Mbata *et al*., 2012; Negahban *et al*., 2012; Nguemtchouin *et al*., 2013; Olivero-Verbel *et al*., 2013; Wakil *et al*., 2012; Ziaee and Moharrmipour, 2012) and seed borne fungi (Cardiet *et al*., 2012), but prospects for the use as alternatives to MB are limited.

The following table presents information from some of the more recent publications indicating the species of investigated plants and their essential oils. The information on the constituents of the oils reveal that often enough the same compounds are repoted from different pants.

Recently, Tapondjou (2014) gave an excellent overview on the subject, describing many of these botanical chemicals with their potential against insects and fungi. Alltogether 656 plant species from 110 families (especially Lamiaceae) and 119 chemical compounds distributed in 11 structural group types among which 3 (terpenoids, alkaloids and phenolic compounds) seem to possess strong insecticidal activity, have so far been cited in the literature (Boulogne *et al.*, 2012, cited in Tapondjou). In this paper, it is also mentioned that 1064 plant species from 150 families (especially Lamiaceae and Fabaceae), and 284 chemical compounds with 11 types of structure (especially terpenoids, alkaloids and phenolic compounds) bring along antifungal activity. So, in the future it may be interesting if a registration of some of these compounds could be promising as azadirachtin from neem oil or pyrethrum from chrysanthemum.

TABLE 6-3. SELECTED RECENT REFERENCES ON COMPOSITION AND LETHAL AND OTHER PHYSIOLOGICAL EFFECTS ON STORED PRODUCT PEST INSECTS

Plants/essential oils	**Investigated aspects**		
Essential oils Egyptian plants	composition toxicity	*Sitophilus oyzae* *Tribolium castaneum*	Abdelgaleil *et al*. 2012
Medicinal plants	toxicity	*Tribolium castaneum*	Akrami & Moharrmipour, 2012
Botanical substances	toxicity	*Sitophilus oryzae* *Aspegillus westerdijkiae* *Fusarium graminearum*	Cardiet et al., 2012
Eucalytus camaldulensis *Eucalyptus leucoxylon*	Composition toxicity	*Callosobruchus maculatus* *Bruchus lentis* *Bruchus rufimanus*	Haouell *et al*., 2012
Eucalytus camaldulensis	Composition toxicity	*Ectomyelois ceratoniae*	Jemâa *et al*., 2012, 2013
Eucalytus transcontinentalis	Composition toxicity	*Eggs and adults Ectomyelois ceratoniae*.	Khemira et al., 2012
synthetic monoterpenoids: anethole, estragole, carvone, linalool, fenchone,geraniol, terpinene, camphor	oviposition deterrence and mortality	*Callosobruchus maculatus*	Mbata *et al.,* 2012
Essential oils	as repellents	*Tribolium castaneum*	Olivero-Verbel *et al*., 2013
Acacia nilotica *Calotropis procera* *Dodonaea viscosa* *Cassia fistula* *Ocimum basilicum* *Adhatoda vasica* *Ziziphus jujuba*	toxicity	*Tribolium castaneum* *Rhzopertha dominica* *Cryptolestes ferrugineus* *Liposcelis paeta*	Wakil et al., 2012
Carum copticum	toxicity	*Sitophilus granarius*	Ziaee and Moharrmipour, 2012.

6.7.7. Integated Pest Management

The concept of integrated pest and commodity management has been further described (Jayas and Jian, 2012; Plarre, 2013; Vital *et al*., 2012) and possible ways to attract or repel pest insects (Ndomo *et al*., 2012). Within this frame, the use of organisms against pest organisms, offers ways of preventing the occurrence of pests in stored products and also empty structures where products are supposed to be stored in the near future. In so far, MB replacement not only focusses on finding alternative fumigants to control the pests when they have appeared. Modern strategies concentrate on approaches where the infestation itself is limited at an early stage to prevent later mass growth and necessities for acute and immediate control. Biological control addresses the need of finding ways to attack the first intruders into a storage system. Schöller and Prozel (2014) give a broad overwiew on the species of antagonists that are commercially available in Germany for this purpose.

6.8. References

Abbar, S., Schilling, M. W., Phillips, T. W. 2012. Protecting hams from the mite *Tyrophagus putrescentiae* using food safe approaches. In: Obenauf, G. L. (ed.), Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 6-8 November in Orlando, Fl, USA, MBAO conference, www.mbao.org, 44-1.

Abbar, S., Zhao, Y., Schilling, M. W, Phillips, T. W. 2013. Chemical alternatives for suppressing the ham mite, *Tyrophagus putrescentiae*. In: Obenauf, G. L. (ed.), Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 3-7 November in San Diego, CA, USA, MBAO conference. www.mbao.org, 44-1.

Abdelgaleil, S. A. M., Badawy, M. E. I., Mohammed, M. I. E., Shawir, M. S. 2012. Chemical composition and fumigant toxicity of essential oils isolated from Egyptian plants aginst stored product insects *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst). Navarro et al., 2012a, 50-57.

Adler, C., Corinth, H.-G., Reichmuth, Ch. 2000. Modified atmospheres. In: Subramanyam, B., Hagstrum, W. H. (eds.), Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, 437 pp, 105-146.

Adler, C., Murray, A. 2012. Taking the tropics home: Controlled atmospheres for the control of tobacco beetles in large scale testing. Navarro et al., 2012a, 488-494.

Adler, C., Reichmuth, Ch. 2013. Untersuchungen zur Abtötung der Dörrobstmotte Plodia interpunctella und des Brotkäfers *Stegobium paniceum* mit Kälte bei -10°C, -14°C und -18°C [Studies to control the Indianmeal moth *Plodia interpunctella* and the drugstore beetle *Stegobium paniceum* with subzero temperatures of -10°C, -14°C and -18°C]. (online: www.JKI.de), Journal für Kulturpflanzen 65, 110-117.

Ahnadi, M., Moharramipour, S. 2012. Toxicity of *Rosmarinus officinales* essential oil against irradiated *Tribolium castaneum*. Navarro et al., 2012a, 295-299.

Akan, K., Ferizli, A. G. 2010. Does sulfuryl fluoride and heat combination overcome the egg-weakness of almond moth? In: Obenauf, G. L. (ed.), Proceedings of the Annual International Reserarch Conference on Methyl Bromide Alternatives and Emissions Reductions, 2-5 November in Orlando, Fl, USA, MBAO conference, www.mbao.org, 56-1 - 56-4.

Akrami, H., Moharrmipour, S. 2012. Fumigant toxicity of two medicinal plant essential oils on *Tribolium castaneum* (Herbst). Navarro et al., 2012a, 91-95.

Aksoy, U., Sen, F., Meyvaci, K. B. 2012. Effect of post-harvest carbon dioxide on storage pests and fruit quality of dried figs. Navarro et al., 2012a, 166-171.

Amoah, B., Schilling, M. W., Phillips, T. W. 2012a . Protecting hams from the mite *Tyrophagus putrescentiae* using food-safe approachges. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 6-8 November in Orlando, Fl, USA, MBAO conference, www.mbao.org, 44-1.

Amoah, B., Schilling, M. W., Phillips, T. W. 2012b. IPM as alternative for the ham mite *Tyrophagus putrescentiae*: monitoring with traps. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 6-8 November in Orlando, Fl, USA, MBAO conference, www.mbao.org, 45-1.

Amoah, B., Schilling, M. W., Phillips, T. W. 2013. Trapping the ham mite, *Tyrophagus putrescentiae*, with a food bait: Toward a monitoring tool for IPM. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 3-7 November in San Diego, CA, USA, MBAO conference, www.mbao.org 37-1.

Andres, A. B. 2013. Alternative Treatments to Phosphine Plates Fumigation in Controlling Cigarette Beetles (*Lasioderma serricorne*) of Stored Expanded Tobacco (ET). MEGA MANILA PEST MANAGEMENT SPECIALISTS INC. Confidential Industrial Report.

Andres, A. B. 2013. Evaluating Resistance to Phosphine of Cigarette Beetles Collected from Philip Morris International Warehouse in Subic, Olongapo City, Philippines. MEGA MANILA PEST MANAGEMENT SPECIALISTS INC. Confidential Industrial Report.

Arysta, 2013. Announcement with regard to methyl iodide – business transfer to Izutsuya Chemical Industries Japan – 8 October 2013, Arysta life sciences Corporation (in Japanese, http://www.agrofrontier.com/yoka/pdf/yoka20131008.pdf).

Asher, P. 2012 Phosphine resistance and solutions. Navarro et al., 2012a, 658.

Athanassiou, Ch. G., Kavallieratos, N.G., Isikber, A. A., Oztekin, M. S. 2014. Insecticidal effect of ozone agaist different life stages of *Plodia interpunctella*, *Tribolium confusum*, *Cryptoestes ferrugineus* and *Oryzaephilus surinamensis*. In: Athanassiou et al. 2014, 224.

Athanassiou, Ch. G., Pasquale Trematerra, P., Kavallieratos, N. G., Weintraub, Ph., G. (eds.) 2014. Proceedings of the meeting of the IOBC, Integrated Protection of Stored Products, 1-4 July 2013 in Bordeaux, France, International Organization for Biological and Integrated Control of Noxious Animals and Plants, West Palearctic Regional Section (IOBC-WPRS), Darmstadt, ISBN 978-92-9067-277-7, http://www.iobc-wprs.org, IOBC-WPRS Bulletin 98, 466 pp,

Athanassiou, Ch., Phillips, T., Aikins, M. J., Hasan, M. M., Throne, J. 2012. Effectiveness of sulfuryl fluoride for control of different life stages of stored-product psocids (Psocoptera). Journal of Economic Entmology 105, 282-287.

Aulicky, R., Kucerova, Z., Stejskal, V. 2012. Control of brown-legged mite adults using nitrogen atmosphere. Navarro et al., 2012a, 545-548.

Baltaci, D., Klementz, D., Gerowitt, B., Drinkall, M., Reichmuth, Ch. 2006. Sulfuryl difluoride to control toward premature life stages of *Ephestia elutella* (Hübner). In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 6-9 November in Orlando, Fl, USA, MBAO conference, www.mbao.org106-1–106-4.

Baltaci, D., Klementz, D., Gerowitt, B., Drinkall, M., Reichmuth, Ch. 2008. Sulfuryl fluoride against all life stages of rust-red grain beetle (*Cryptolestes ferrugineus*) and merchant grain beetle (*Oryzaephilus mercator*). In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, November 11-14 in Orlando, FL, USA, MBAO conference, www.mbao.org, 87-1 – 87-3.

Baltaci, D., Klementz, D., Gerowitt, B., Drinkall, M., Reichmuth, Ch. 2009. Lethal effects of sulfuryl fluoride on eggs of different ages and other life stages of the warehouse moth *Ephestia elutella* (Hübner). Journal of stored Products Research 45, 19-23.

Banks, J. 2012. Long term semi-underground hermetic storage of grain. Navarro et al., 2012a, 440-449.

Barakat, D.A., Klementz, D., Reichmuth, Ch. 2009. Response of eggs of *Corcyra cephalonica* towards sulfuryl fluoride. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 29 Oct - 1 November in San Diego, CA, USA, MBAO 61-1 – 61-4. Available online at: http://mbao.org/2009/061Reichmuth.pdf.

Beckett, S.J., Darby, J.A., Forrester, R.I. 2010. The effect of diurnally interrupted doses of phosphine over four days on egg mortality of susceptible and resistant strains of *Sitophilus oryzae* (L.). Journal of stored Products Research 46, 59-65.

Bell C. H. 2014a. Food Safety Assurance Systems: Infestation Management in Food Production Premises. In: Motarjemi, Y., Moy, G., Todd, E. (eds.), Encyclopedia of Food Safety, Volume 4, Waltham, M. A., Academic Press, 189-200.

Bell, C. H. 2006. Factors affecting the efficacy of sulphuryl fluoride as a fumigant. In: Lorini, I. et al. (eds.), Proceedings of the 9th International Working Conference on Stored Product Protection, 15 - 18 October in Campinas, Sao Paulo, Brazil. Brazilian Post-harvest Association - ABRAPOS, Passo Fundo, RS, Brazil, 519-526.

Bell, C. H. 2013. Pest Management. In: Motarjemi, Y., Stadler, R., Lelieveld, H. (eds.), Food Safety Management: A Practical Guide for the Food Industry, Elsevier, 799-820.

Bell, C. H. 2014b. Pest control of stored food products: insects and mites. In: Leileveld, H. L. M., Holah, J., Napper, D. (eds.), Hygiene in Food Processing: Principles and Practice (2nd ed.), Woodhead Publishing Ltd, 494-538.

Bell, C. H. 2014c. Physical and chemical control agent thresholds for action on storage insects. Integrated Protection of Stored Products, IOBC-WPRS Bulletin 98, 299-308.

Bell, C. H., Savvidou, N. 1999. The toxicity of Vikane (sulfuryl fluoride) to age groups of the Mediterranean flour moth (*Ephestia kuehniella*). J. Stored Products Research 35, 233-247.

Bell, C. H., Savvidou, N., Wontner Smith, T. J. 1999. The toxicity of sulfuryl fluoride (Vikane) to eggs of insect pests of flour mills. In: Zuxun, J., Quan, L., Yongsheng, L., Xianchang, T., Lianhua, G. (Eds.), proceedings of the 7th International Working Conferece on Stored-Product Protection, 14-19 October 1998 in Beijing, P. R. China, Sichuan Publishing House of Science & Technology, Oct. 1999, Chengdu Province, P. R. China, Vol. 1, 345-350.

Bell, C. H., Wontner-Smith, T. J., Savvidou, N. 2003. Some properties of sulphur fluoride in relation to its use as a fumigant in the cereals industry. In: Credland, P. F., Armitage, D. M., Bell, C. H., Cogan P. M., Highley, E. (eds.), Advances in Stored Product Protection, Proceedings of the 8th International Working Conference on Stored Product Protection, 22-26 July in York, UK, CAB International, London, 910-915.

Biebl, S., Reichmuth, Ch. 2013. Stickstoff-Behandlung gegen Materialschädlinge [Nitrogen against material pests]. (online: www.JKI.de), Journal für Kulturpflanzen 65, 99-109.

Boulogne, I., Petit, P., Lafontaine, H. O., Desfontaines, L., Merciris, G. L. 2012. Insecticidal and antifungal chemicals produced by plants: a review. Environ. Chem. Lett. 10, 325-347.

Bridgeman, B., Collins, P. 2012. Resistance management in stored products fumigation. Navarro et al., 2012a, 633-637.

Buckley, S., Drinkall, M. 2010. Adoption of sulfuryl fluoride for the control of stored product insects in Europe and future development. Julius-Kühn-Archiv 425, 15-18.

Buckley, S., Thoms, E. 2012. Current status of PROFUME® gas fumigant for disinfestations of commodities. Navarro et al., 2012a, 241-246.

Calderon, M., Barkai-Golan, (eds.) 1990. Food Preservation by Modified Atmospheres. CRC Press, Boca Raton FL, USA, 402 pp.

Campbell, J. F., Toews, M. D., Arthur, F. H., Arbogast, R. T. 2010. Structural fumigation efficacy against *Tribolium castaneum* in flour mills. In: Cavalho, M. O., Fields, P. G., Adler, C. S., Arthur, F. H., Athanassiou, C. G., Campbell, J. F., Fleurat-Lessard, F., Flin, P. W., Hodges, R. J., Isikber, A. A., Navarro, S., Noyes, R. T., Riudavets, J., Sinha, K. K., Thorpe, G. R., Timlick, B. H., Trematerra, P., White, N. D. G. (eds.), Proceedings of the 10th International Working Conference on Stored Product Protection, 27 June – 2 July 2010 in Estoril, Portugal, Julius-Kühn-Archiv 425, Vol. 1, ISBN 978-3-930037-71-1, pdf online: www.jki.bund.de, 352-357.

Campbell, P.M. 2010. Comparison of the mitochondrial proteomes of phosphine-susceptible and –resistant *Tribolium castaneum*. Journal of stored Products Research 46, 197-201.

Campolo, O., Verdone, M., Laudani, F., Malacrino, A., Chiera, E., Palmeri, V. 2013. Response of four stored products insects to a structural heat treatment in a flour mill. Journal of stored Products Research 54, 54-58.

Cardiet, G., Fleurat-Lessard, F., Barreau, Ch. 2012. Fumigant toxicity of some volatile botanical substances against the wheat pest *Sitophilus oryzae* and two seed-born fungi, *Aspergillus westerdijkiae* and *Fusarium graminearum*. Navarro et al., 2012a, 81-90.

Cavalho, M. O., Barbosa, A., Barros, G., Magro, A., Adler, C., Navarro, S., Riudavets, Y., Timlick, B. 2012. Quality preservation of stored rice, using modified atmospheres in Portugal. Navarro et al., 2012a, 156-165.

Channnaiah, L., Wright, Ch., Subramaniam, B., Maier, D. E. 2012. Evaluation of chlorine dioxide gas against eggs, larvae, and adults of Tribolium castaneum and Tribolium confusum. Navarro et al., 2012a, 403-407.

Chayaprasert, W., Maier, D.E., Subramanyam, B., Hartzer, M. 2012. Gas leakage and distribution characteristics of methyl bromide and sulfuryl fluoride during fumigations in a pilot flour mill. Journal of stored Products Research 50, 1-7.

Cho, J.-H, Park, C. G., Yoo, M., Kim, B.-S., Lee, B.-H. 2012. Comparative toxicity of ethyl formate for control of pests of sweet persimmons for export. Navarro et al., 2012a, 310-314.

Ciesla, Y., Ducom, P. 2010. Efficacy against eggs of *Tribolium confusum* and *Tribolium castaneum* after fumigation with sulfuryl fluoride (ProFume®) in flour mills. In: Cavalho, M. O., Fields, P. G., Adler,

C. S., Arthur, F. H., Athanassiou, C. G., Campbell, J. F., Fleurat-Lessard, F., Flin, P. W., Hodges, R. J., Isikber, A. A., Navarro, S., Noyes, R. T., Riudavets, J., Sinha, K. K., Thorpe, G. R., Timlick, B. H., Trematerra, P., White, N. D. G. (eds.), Proceedings of the 10th International Working Conference on Stored Product Protection, 27 June – 2 July 2010 in Estoril, Portugal, Julius-Kühn-Archiv 425, Vol. 1, ISBN 978-3-930037-71-1, pdf online: www.jki.bund.de, Julius-Kühn-Archiv 425, 48-51.

Ciesla, Y., Ducom, P., Reichmuth, Ch., Walse, S. 2009. Harvest and disinfestation of Deglet Noor dates in Coachella Valley (California). Unpublished report for UNEP, 14 November 2009.

Ciesla, Y., Guéry, B. 2014. Efficacy of diatomaceous earth against the rice weevil *Sitophilus oryzae* (L.) after a preventive treatment of wheat. In: Athanassiou et al., 183-191.

Ciesla, Y., Guéry, B., Ducom, P. 2012. Efficacy of methyl iodide, sulfuryl fluoride and cypermethrin against the six-toothed bark beetle *Ips sexdentatus* (Börner). Navarro et al., 2012a, 254-259.

Corinth, H.-G., Reichmuth, Ch. 2013. Kohlendioxid unter atmophärischem und hohem Druck [Carbon dioxide under atmospheric and high pressure]. (online: www.JKI.de, Veröffentlichungen, Nachrichtenblatt und Journal für Kulturpflanzen), Journal für Kulturpflanzen 65, 94-98.

Daglish, G. J., Nayak, M. K., Pavic, H. 2104. Phosphine resistance in *Sitophilus oryzae* (L.) from eastern Australia: inheritance, fitness and prevalence. Journal of stored Products Research 59, in press.

De Bruin, T., Navarro, S., Villers, P., Wagh, A. 2012. Worldwide use of hermetic storage for the preservation of agricultural products. Navarro et al., 2012a, 450-458.

Dojchinov, G., Damcevski, K., Woodman, J., Haritos, V. 2009. Field evaluation of vaporised ethyl formate and carbon dioxide for fumigation of stored wheat. Wiley Interscience, July 2009.

Drinkall M. J., Zaffagnini, V., Süss, L., Locatelli, D. P. 2003. Efficacy of sulfuryl fluoride on stored-product insects in a semolina mill trial in Italy. In: Credland, P. F., Armitage, D. M., Bell, C. H., Cogan P. M., Highley, E. (eds.), Advances in Stored Product Protection, proceedings of the 8th International Working Conference on Stored Product Protection, 22-26 July in York, UK, CAB International, London, 884-887.

Drinkall, M. J., Dugast, J. F., Reichmuth, Ch., Schöller M. 1996. The activity of the fumigant sulfuryl fluoride on stored product insects. In: Wildey, K. B. (ed.), Proc. 2nd International Conference on Insect Pests in the Urban Environment, 7-10 July in Edinburgh, Scotland, UK, 525-528.

Ducom, P. 2012. Methyl bromide alternatives. Navarro et al., 2012a, 205-214.

Ducom, P., Dupuis, S., Stefanini, V., Guichard, A. A. 2003. Sulfuryl fluoride as a new fumigant for the disinfestations of flour mills in France. In: Credland, P. F., Armitage, D. M., Bell, C. H., Cogan P. M., Highley, E. (eds.), Advances in Stored Product Protection, proceedings of the 8th International Working Conference on Stored Product Protection, 22-26 July in York, UK, CAB International, London, 900-903.

Ducom, P., Frérot, E., Reichmuth, Ch. 2014. Relative importance of fumigation in integrated management of stored-grain insect pests in some EU countries (France and Germany). In: Athanassiou et al., 2014. 275-294.

EPA, 2011. Sulfuryl Fluoride; Proposed Order Granting Objections to Tolerances and Denying Request for a Stay. Federal Register Vol. 76 No 12 Page 3444.

FAMIC, 2014. Agrochemical database in Japan, Food and Agricultural Materials Inspection Center (in Japanese, http://www.acis.farmic.go.jp/index_kensaku.htm).

Fields, P. G. 2012. Novel fumigants and heat treatments for flour mills. Navarro et al., 2012a, 333-344.

Finkelman, S., Lendler, E., Navarro, S., Navarro, H., Ashbell, G. 2010. New prospects for ethyl formate as a fumigant for the date industry. 10th International Working Conference on Stored Product Protection. Julius-Kühn-Archiv 425, 359-364.

Finkelman, S., Navarro, S., Navarro, H., Lendler, E. 2012. “VAPORMATETM” an alternative fumigant for QPS treatments. Navarro et al., 2012a, 247-253.

Fleurat-Lessard, F., Fuzeau, B. 2014. High-Temperature-Short-Time (HTST) disinfestation of wheat grain infested by *Sitophilus* spp. pre-emergent stages with a laboratory scale fluidized-bed. In: Athanassiou et al., 213-222.

Flingelli, G., Schöller, M., Klementz, D. W., Reichmuth, Ch. 2014. Einfluss von Temperatur und Expositionsdauer auf die Mortalität von *Tribolium castaneum* Eiern unter Begasung mit Sulfurylfluorid im Hinblick auf die fortschreitende Entwicklung [Influence of temperature and exposure time on the mortality of *Tribolium castaneum* eggs during fumigation with sulfuryl fluoride with regard to the progressive egg development.] (online: www.JKI.de), Journal für Kulturpflanzen 66, 7-14.

Flingelli, G., Schöller, M., Reichmuth, Ch. 2012. Efficacy of sulfuryl fluoride towards eggs of *Tribolium castaneum* (Herbst, 1797). In : Proceedings of the Conference on General and Applied Entomology, 21-24 March 2011 in Berlin, Germany, Mitteilungen der deutschen Gesellschaft für allgemeine und angewandte Entomologie 18, online: http://www.dgaae.de, 447-450.

Floréal, D., Baslé, K., Mounier, A., Queixalos, I., Robbiola, L., Ducom, P., Ciesla, Y., Fritsch, J. 2012. The disinfestations of historical monuments: Gas substitutes for methyl bromide. Navarro et al., 2012a, 222-230.

Gautam, S. G.; Opit, G. O., Walse, S. 2013. Efficacy of propylene oxide in combination with carbon dioxide against eggs of stored-product insect pests. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 3-7 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 29-1.

Guogang, X., Guangli, S., Shengjie, J., Jiade, S., Lichao, J., CaiFeng, Ch., Guanghui, Sh. 2008. Application researches on fumigation by combination of sulfuryl fluoride and carbon dioxide in cereals. In: Daolin, G., Navarro, S., Jian, Y., Chang, T., Zuxun. J., Yue, L., Yang, L., Haipeng, W. (eds.), Proceedings of the 8th International Conference on Controlled Atmosphere and Fumigation in Stored Products, 21-26 September 2008 in Chengdu, China. Sichuan Publishing Group, Sichuan Publishing House of Science and Technology, Chengdu, China, 233-237.

Hallman, G.J. 2013. Control of stored product pests by ionising radiation. Journal of stored Products Research 52, 36-41.

Haouell, S., Khouja, M. L., Boudabous, A., Jemâa, J. M. B. 2012. Use of eucalyptus essential oils as fumigants for the control of three stored food legume weevils. Navarro et al., 2012a, 71-75.

Hardin, J.A., Jones, C.L., Bonjour, E.L., Noyes, R.T., Beeby, R.L., Eltiste, D.A., Decker, S. 2010. Ozone fumigation of stored grain; closed loop recirculation and the rate of ozone consumption. Journal of stored Products Research 46, 149-154.

Hartzer, M., Subramanyam, B., Brijwani, M. Chayaprasert, W., Maier, D. E. 2010a. Methyl bromide, sulfuryl fluoride and heat: effectiveness against red flour beetle. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Reserarch Conference on Methyl Bromide Alternatives and Emissions Reductions, 2-5 November in Orlando, Fl., USA, MBAO conference, www.mbao.org, 67-1 – 67-4.

Hartzer, M., Subramanyam, B., Chayaprasert, W., Maier, D. E., Savoldelli, S., Campbell, J. F., Flinn, P. W. 2010b. Methyl Bromide and sulfuryl fluoride effectiveness agaist red flour beetle life stages. In: Daolin, G., Navarro, S., Jian, Y., Chang, T., Zuxun. J., Yue, L., Yang, L., Haipeng, W. (eds.), Proceedings of the 8th International Conference on Controlled Atmosphere and Fumigation in Stored Products, 21-26 September 2008 in Chengdu, China. Sichuan Publishing Group, Sichuan Publishing House of Science and Technology, Chengdu, China, Julius-KühnArchiv 429, 365-370.

Hasan, M. M., Phillips, T. W., Aikins, M. J. 2012. Potential for ozone fumigation against anobiid beetles infesting stored products as an alternative to methyl bromide. Navarro et al., 2012a, 260-265.

Huiyi, Z., Yang, C., Hongqin, Z., Yanyu, L., Jie, L., Jin, L. 2012. Comparison with pressure swing adsorption and membrane separation nitrogen for reduce oxygen at stored grain in horizontal warehouse. Navarro et al., 2012a, 509-516.

Jayas, D., Jian, F. 2012. Integrated commodity management. Navarro et al., 2012a, 705-714.

Jeffers, L. 2014. PPQ Phytosanitary irradiation program. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 4-6 November in Orlando, FL, USA, MBAO conference, www.mbao.org, MBAO Paper 43.

Jemâa, J. M. B, Haouel, S., Khouja, L. 2012. Control of the carob moth *Ectomyelois ceratoniae* with essential oil fumigation. Navarro et al., 2012a, 58-62.

Jemâa, J. M. B., Haouel, S., Khouja, M. L. 2013. Efficacy of Eucalyptus essential oils fumigant against *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) under various space occupation conditions. Journal of stored Product Research 49, 67-71.

Jiao, S., Johnson, J. A., Tang, J., Wang, S. 2012. Industrial scale radio frequency treatments for insect control in lentils. Journal of stored Products Research 48, 143-148.

JIIDCP, 2014. Approved chemicals list for the treatment of cultural heritages, Japan Institute of Insect Damage to Cultural Properties (in Japanese, http://www.bunchuken.or.jp/chemical/).

Karakoyun, N. S., Emekci, M. 2010. The efficacy of sulfuryl fluoride against egg stages of dried fruit beetle. In: Obenauf, G. L. (ed.), proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 2-5 November in Orlando, Fl., USA., MBAO conference, www.mbao.org, 55-1 – 55-4.

Kaur, R., Schlipalius, D.I., Collins, P.J., Swain, A.J., Ebert, P.R. 2012. Inheritance and relative dominance, expressed as toxicity response and delayed development, of phosphine resistance in immature stages of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae). Journal of stored Products Research 51, 74-80.

Kenaga, E. E. 1957. Some biological, chemical and physical properties of sulfuryl fluoride as an insecticidal fumigant. Journal of economic Entomology 40, 1-6.

Khemira, S., Jemâa, J. M. B., Khouija, M. L. 2012. Fumigant toxicity of *Eucalyptus transcontinentalis* essential oil against eggs and adults of the carob moth *Ectomyelois ceratoniae*. Navarro et al., 2012a, 325-328.

Klementz, D., Rassmann, W., Reichmuth, Ch. 2008. Sulfuryl fluoride – efficacy against *Tribolium castaneum* and *Ephestia kuehniella* and residues of the gas in flour after fumigation of mills. In: Daolin, G., Navarro, S., Jian, Y., Chang, T., Zuxun. J., Yue, L., Yang, L., Haipeng, W. (eds.), Proceedings of the 8th International Conference on Controlled Atmosphere and Fumigation in Stored Products, 21-26 September 2008 in Chengdu, China. Sichuan Publishing Group, Sichuan Publishing House of Science and Technology, Chengdu, China, 533-537.

Korunic, Z., Kalinovic, I., Rozman, V., Loska, A. 2012. One-year protection of stored wheat with several grain protectants. Navarro et al., 2012a, 715-720.

Kucerova, Z., Kyhos, K., Aulicky, R., Stejskal, V. 2012. Improvementof vacuum effect on mortality of *Sitophilus granarius* (Curculionidae) using oxygen chemical absorber in laboratory conditions. Navarro et al., 2012a, 76-80.

Kurlanski, M., Salt: A world history. 2002. Penguin Books, 484 pp.

Lawrence, J., Subramaniam, B., Meier, D. E., Chayaprasert, W. 2012. Efficacy of sulfuryl fluoride against eggs and adults of *Tribolium castaneum* in commercial flour mills. Navarro et al., 2012a, 291.

Lehms, M., Baier, B., Wurst, S., Schöller, M., Reichmuth, Ch. 2012: Zum Eiablageverhalten der vorratsschädlichen Milben *Acarus siro* **und** *Tyrophagus putrescentiae* auf verschiedenen Substraten und durch feinmaschige Gaze [Egg laying behaviour of the stored product pest mites *Acarus siro* and *Tyrophagus putrescentiae* on different substrates and through fine mesh Nylon gauze]. In: Julius Kühn-Institut (ed.), Julius-Kühn-Archiv 438, Proceedings of the 58th Deutsche Pflanzenschutztagung, 10 - 14 September 2012 in Braunschweig, Germany, ISBN 978-3-30037, http://pub.jki.bund.de/index.php/JKA/ article/view/670/2244, 500 pp., 75.

Linde 2013 http://cropscience.linde-gas.com/en/products_services/vapormate.html

Ling, Z., Xinfu, Z., Qing, X., Jiadong, Ch. 2008. Efficacy of sulfuryl fluoride on stored grain pests in a warehouse trial in China. In: Daolin, G., Navarro, S., Jian, Y., Chang, T., Zuxun. J., Yue, L., Yang, L., Haipeng, W. (eds.), Proceedings of the 8th International Conference on Controlled Atmosphere and Fumigation in Stored Products, 21-26 September 2008 in Chengdu, China. Sichuan Publishing Group, Sichuan Publishing House of Science and Technology, Chengdu, China, 579-582.

Liu, Y.-B. 2013a. Nitric oxide as a potent fumigant for postharvest pest control. J. Econ. Entomology 106: 2267-2274.

Liu, Y.-B. 2013b. Prospect of no fumigation for postharvest pest control. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 3-7 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 28-1 – 28-3.

Malushkov, G., Prokopov, D., Tikhonova, L. 2012. Active cell phosphine generator SGF-M2 and fumigation technologies with its use. Navarro et al., 2012a, 353-357.

Manickavasagan, A., Alahakoon, P. M. K., Al-Busaidi, T. K., Al-Adawi, S., Al-Wahaibi, A. K., Al-Raeesi, A. A., Al-Yahyai, R., Jayas, D. S. 2013. Disinfestation of stored dates using microwave energy. Journal of stored Products Research 55, 1-5.

Mbata, G. N., Smith, D., Mcneal, K. 2012. Monoterpenoids as fumigants in the management of *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) oviposition deterrence and mortality of developmental stages. Navarro et al., 2012a, 44-49.

MBTOC 2007. 2006 Assessment Report of the Methyl Bromide Technical Options Committee. UNEP, Nairobi, online: ozone.unep.org, 482 pp.

MBTOC 2011a. 2010 Assessment Report of the Methyl Bromide Technical Options Committee. UNEP, Nairobi, online: ozone.unep.org, 398 pp.

MBTOC 2011b. Progress Report 2011, Special Review on achieving control of pest eggs by sulfuryl fluoride. In: TEAP Progress Report, May 2011, 245 pp, online: ozone.unep.org, 108- 136.

McClurkin, J. D., Maier, D. E., Ileleji, K. E. 2013. Half-life time of ozone as a function of air movement and conditions in a sealed container. Journal of stored Products Research 55, 41-47.

Meikle, R. W., Stewart, D., Globus, O. A. 1963. Drywood termite metabolism of Vikane fumigant as shown by labelled pool technique. Journal of Agriculture, Food and Chemistry 11, 226-230.

Mück, O., Stock, A. 2012. Occupational safety in import containers containing fumigants, other gases and volatile substances: Practical experiences. Navarro et al., 2012a, 193-197.

Muhareb, J. 2009. Evaluation of combining sulfuryl fluoride, propylene oxide and carbon dioxide for stored product insect control. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 11-13 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 64-1 – 64-2.

Naik, R. C., Shroff, R. D. 2012a. NDIR based SO_2F_2 detector for fumigation monitoring. Navarro et al., 2012a, 374-378.

Naik, R. C., Shroff, R. D. 2012b. Automatic online phosphine monitoring system for fumigation. Navarro et al., 2012a, 596-599.

Navarro S., Finkelman S., Rindner M., Dias R., 2004. Heat treatment for disinfestation of nitidulid beetles from dates. In: Batchelor, T., Alfarroba, F. (eds), Proceedings of the International Conference on Alternatives to Methyl Bromide, 27-30 September 2004 in Lisbon, Portugal, 297-300.

Navarro, S. 2012. Global challenges for the successful application of MA and hermetic storage. Navarro et al., 2012a, 429-439.

Navarro, S., Athanassiou, Ch., Varnava, A., Vroom, N., Yilasoumis, D., Leandrou, I., Hadjiannou, S. 2012b. Control of stored grain insects by using nitrogen in large concrete silos in Cyprus. In: Navarro et al., 2012a, 478-487.

Navarro, S., Banks, H. J., Jayas, D. S., Bell, C. H., Noyes, R. T., Ferizli, A. G., Emecki, M., Isikber, A. A., Alagusundaram, K. (eds.) 2012a. Proceedings of 9th International Conference on Controlled Atmosphere and Fumigation in Stored Products, 15-19 October 2012 in Antalya, Turkey744 pp., www.caf2012.org.

Navarro, S., Navarro, H., Finkelmann, S. 2014. Mortality of *Carpophilus hemipterus* eggs and larvae under the influence of thermal disinfestation. In: Athanassiou et al., 159-165.

Nayak, M. K. 2012. Managing resistance to phosphine in storage pests: Challenges and opportunities. Navarro et al., 2012a, 609-619.

Negahban, M., Moharrmipour S., Zandi, M., Hashemi, S. A. 2012. Fumigant properties of nano-encapsulated essential oil from *Artemisia sieberi* on *Tribolium castaneum.* Navarro et al., 2012a, 101-105.

Newman, Ch. R., Emery, N. N., Chami, M. 2012c. Eradication of a strain of a strong phosphine resistant insect population from steel farm silos in Western Australia. Navarro et al., 2012a, 644-652.

Newman, Ch., Newman, J., Cheng, H., Ren, Y. 2012a. Investigation of thermosiphons pipes to distribute phosphine gas through garin silos from ground level introduction point. Navarro et al., 2012a, 557-570.

Newman, Ch., Newman, J., Cheng, H., Ren, Y. 2012b. An experimental procedure to eradicate strong phosphine resistant grain insects from unsealed steel silos using ethyl formate. Navarro et al., 2012a, 661-664.

Nguemtchouin, M. G. M., Ngassoum, M. B, Chalier, P., Kamga, R., Ngamo, L. S. T., Cretin, M. 2013. *Ocimum gratissimum* essential oil and modified montmorillonite clay, a means of controlling insect pests in stored products. Journal of stored Products Research, 49, 57-62.

Noomhorm, A., Sirisoontaralak, P., Uraichuen, J., Ahmad, I. 2013. Efficacy of atmospheric and pressurized carbon dioxide or air against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) and *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in milled rice. J. Stored Products Research 54, 48-53.

Noppe, H., Buckley, S., Ruebsamen, B. 2012. Possibilities of PROFUME gas fumigant for the commercial fumigation of stored cocoa beans in EU. Navarro et al., 2012a, 379-383.

Olivero-Verbel, J., Tirado-Bellestas, I., Caballero-Gallardo, K., Stashenko, E. E. 2013. Essential oils applied for the food act as repellents towards *Tribolium castaneum*. J. Stored Products Research 49, 145-147.

Osbrink, W. L. A., Scheffrahn, R. H., Hsu, R.-C., Su, N.-Y. 1988. Sulfuryl fluoride residues of fumigated foods protected by polyethylene film. Journal of Agriculture and Food Chemistry 36, 853-855.

Outram, I. 1967a. Factors affecting the resistance of insect eggs to sulphuryl fluoride – The uptake of sulphuryl^{35}S fluoride by insect eggs. Journal of stored Products Research 3, 255-260.

Outram, I. 1967b. Factors affecting the resistance of insect eggs to sulphuryl fluoride – II: The distribution of sulphuryl^{35}S fluoride in insect eggs after fumigation. Journal of stored Products Research 3, 353-358.

Park, Ch.-G., Cho, J.-H., Yoo, M., Kim, B.-S., Lee, B.-H., Ren, Y.L. 2012. Ethanedinitrile (C_2N_2): Timber and log fumigation update. Navarro et al., 2012a, 421-425.

Phillips, T., and W. Schilling 2013. Fumigation alternatives for the ham mite, *Tyrophagus putrescentiae*: Challenges and prospects. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 3-7 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 38-1.

Phillips, T. W., Hasan, M. M., Aikins, M. J. 2012a. Potential for phosphine and sulfuryl fluoride as replacements for methyl bromide to control pests of dried meat. Navarro et al., 2012a, 280.

Phillips, T. W., Hasan, M. M., Aikins, M. J., Abbar, S., Amoah, B. 2012b. Non-chemical treatments for potential disinfestation of two major arthropod pests of Southern dry-cured hams. Navarro et al., 2012a, 542.

Phillips, T. W., Hasan, M. M., Aikins, M. J., Mahroof, R. 2011. Fumigation and IPM. Alternatives for arthropod pests of museums. J. Ent. Acarol. Res. 43, 205-210.

Phillips, T. W., Hasan, M. M., Aikins, M. J., Schilling, M. W. 2008. Efficacy of sulfuryl fluoride to control ham mites and red-legged ham beetles. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emission Reduction, 11-14 November in Orlando, FL, USA, MBAO conference, www.mbao.org, 89-1 - 89-2.

Phillips, T. W., Opit, G. P., Aikins, M. J., Hasan, M. M. 2012c. Phosphine resistance in major stored grain insects in the USA. Navarro et al., 2012a, 659.

Plarre, R. 2013. Review: More than a pest magement tool – 45 years of practical experience with insect pheromones in stored-product and material protection. Journal of Plant Diseases and Protection 120, 145-152.

Pons, M.J., Camara, A.G., Guri, S., Riudavets, J. 2010. The use o carbon dioxide in big bags and containers for the control of pests in food products. In: Cavalho, M. O., Fields, P. G., Adler, C. S., Arthur, F. H., Athanassiou, C. G., Campbell, J. F., Fleurat-Lessard, F., Flin, P. W., Hodges, R. J., Isikber, A. A., Navarro, S., Noyes, R. T., Riudavets, J., Sinha, K. K., Thorpe, G. R., Timlick, B. H., Trematerra, P., White, N. D. G. (eds.), Proceedings of the 10th International Working Conference on Stored Product Protection, 27 June – 2 July 2010 in Estoril, Portugal, Julius-Kühn-Archiv 425, Vol. 1, ISBN 978-3-930037-71-1, pdf online: www.jki.bund.de, 414- 418.

Pupin, F., Bikoba, V., Biasi, W. B., Pedroso, G. M., Ouyang, Y., Grafton-Cardwell, E., Mitcham, E. J. 2013. Postharvest control of western flower thrips (Thysanoptera: Thripidae) and California red scale (Homoptera: Diaspididae) with ethyl fromate and its impact on citrus fruit quality. Journal of Economic Entomology 106, 2341-2348.

Purohit, P., Jayas, D.S., Yadav, B.K., Chelladurai, V., Fields, P.G., White, N.D.G. 2013. Microwaves to control *Callosobruchus maculatus* in stored mung bean (*Vigna radiata*). Journal of stored Products Research 53, 19-22.

Reichmuth, Ch. 2007a. Fumigants for pest control in wood protection. In: Noldt, U, Michels, H. (eds.), Proceedings of an International Symposium on “Wood Pest Insects in Focus – Alternative Measures to Preserve Historical Buidings”, 28-30 June in Detmold, Germany, Merkur Verlag, Detmold, 265 pp, 137-162.

Reichmuth, Ch. 2007b. Safer and more efficient use of fumigants to reduce the dosage. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Conference on Methyl Bromide Alternatives and Emissions Reductions, (MBAO), 29 October 29 – 1 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 79-1 – 79-2.

Reichmuth, Ch. 2010a. Pest control and constraints in flour mills. In: Reichmuth, Ch. (ed.), International European Symposium on Stored Product Protection „Stress on Chemical Products“, 25-26 May 2009 in Berlin, Julius-Kühn-Archiv 429, online : www.jki.bund.de, 10-13.

Reichmuth, Ch. 2010b. Fumigants in stored product protection. In: Reichmuth, Ch. (ed.), International European Symposium on Stored Product Protection „Stress on Chemical Products“, 25-26 May 2009 in Berlin, Julius-Kühn-Archiv 429, online : www.jki.bund.de, 429, 56-64.

Reichmuth, Ch. 2013. Aussichten für Vorratsschädlinge [Prospects for stored product pests]. (online: www.JKI.bund.de), Journal für Kulturpflanzen 65, 85-93.

Reichmuth, Ch., Klementz, D. 2008a. How to overcome the egg-weakness of sulfuryl fluoride – combination of control methods. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 11-14 November in Orlando, Fl., USA., MBAO conference, www.mbao.org, 88-1 – 88-4.

Reichmuth, Ch., Klementz, D. 2008b. Pest control in stored product and material protection with sulfuryl fluoride. In: proceedings of the Conference on General and Applied Entomology, 26.2. – 1.3. 2007 in Innsbruck, Östereich, Mitteilungen der deutschen Gesellschaft für allgemeine und angewandte Entomologie 16, Giessen, online: http://www.dgaae.de, 309-312.

Reichmuth, Ch., Rassmann, W., Binker, G., Fröba, G., Drinkall, M. J. 2003. Disinfestation of rust-red flour beetle (*Tribolium castaneum*), saw-toothed grain beetle (*Oryzaephilus surinamensis*), yellow meal worm (*Tenebrio molitor*), Mediterranean flour moth (*Ephestia kuehniella*), and Indian meal moth (*Plodia interpunctella*) with sulfuryl fluoride in flour mills. In: Credland, P. F., Armitage, D. M., Bell, C. H., Cogan P. M., Highley, E. (eds.), Advances in Stored Product Protection, Proceedings of the 8th International Working Conference on Stored Product Protection, 22-26 July in York, UK, CAB International, London, 736-738.

Reichmuth, Ch., Schneider, B., Drinkall, M. J. 1999. Sulfuryl fluoride (Vikane) against eggs of different age of the Indian meal moth *Plodia interpunctella* (Hübner) and the Mediterranean flour moth *Ephestia kuehniella* Zeller. In: Zuxun, J., Quan, L., Yongsheng, L., Xianchang, T., Lianhua, G. (Eds.), Proceedings of the 7th International Working Conferece on Stored-Product Protection, 14-19 October 1998 in Beijing, P. R. China, Sichuan Publishing House of Science & Technology, Oct. 1999, Chengdu Province, P. R. China, Vol. 1, 416-422.

Reichmuth, Ch., Unger, A., Unger, W., Blasum, G., Piening, H., Rohde-Heer, P., Plarre, R., Pöschko, M., Wudtke A. 1993. Nitrogen-flow fumigation fort he preservation of wood, textiles, and other organic material from insect damage. In: Navarro, S., Donahaye, E. (eds.), Proceedings of an International Conference on Controlled Atmospheres and Fumigation in Grain Storage, 11-13 June 1992 in Winnipeg, Canada, Jerusalem Caspit Press Ltd, 121-128.

Ren, Y. L., Lee, B.-H., Padovan, B. 2011. Penetration of methyl bromide, sulfuryl fluoride, ethanedinitrile and phosphine into timber blocks and the sorption rate of the fumigants. Journal of stored Products Research 47, 63-68.

Ren, Y. L., Mahon, D. 2006. Fumigation trials on the application of ethyl formate to wheat, split faba beans and sorghum in small metal bins. Journal of stored Products Research 42, 277-289.

Ren, Y. L., Yang, C., Newman, J., Agarwal, M., Kostas, E., Cheng, H. 2012. Nitrogen application offers for both control of insect and grain quality. Navarro et al., 2012a, 471-477.

Ridley, A. W., Burrill, P. R., Cook, C. C., Daglish, G. J. 2011. Phosphine fumigation of silo bags. Journal of stored Products Research 47, 349-356.

Ridley, A. W., Schlipalius, D.I., Daglish, G.J. 2012. Reproduction of phosphine resistant *Rhyzopertha dominica* (F.) following sublethal exposure to phosphine. Journal of stored Products Research 48, 106-110.

Riudavets, J., Castañé, C., Alomar, O., Pons, Mª. J., Gabarra, R. 2009. Modified Atmosphere Packaging (MAP) as an alternative measure for controlling nine pests that attack processed food products. Journal of Stored Products Research 45, 91-96.

Riudavets, J., Pons, M.J., Gabarra, R., Castane, C., Alomar, O., Vega, L.F., Guri, S. 2014. The toxicity effects of atmospheres with high content of carbon dioxide with addition of sulphur dioxide on two stored-product pest species. Journal of stored Products Research 57, 58-62.

Ryan, R. F., Shore, W. P. 2012. The use of gaseous phosphine by onsite mixing. Navarro et al., 2012a, 358-362.

Sabio, G. C., Dator, J. V., Austria, M. C., Mesa, V. G. 2102. Laboratory studies on the application of hermetic storage for preserving arabica coffee. Navarro et al., 2012a, 523-534.

Sánchez-Ramos, I., Castañera, P. 2005. Effect of temperature on reproductive parameters and longevity of *Tyrophagus putrescentiae* (Acari: Acaridae). Experimental and Applied Acarology 36, 93-105.

Schaub, J. 2010. Five economic principles applied to stored product protection. In: Reichmuth, Ch. (ed.), International European Symposium on Stored Product Protection „Stress on Chemical Products“, 25-26 May 2009 in Berlin, Julius-Kühn-Archiv 429, online: www.jki.bund.de, 429, 23-25.

Scheffrahn, R. H., Hsu, R.-C., Su, N.-Y. 1990. Evaluation of polymer film enclosures as protective barriers for commodities from exposure to structural fumigants. Journal of Agriculture and Food Chemistry 38, 904-908.

Schöller, M. 1998. Biologische Bekämpfung vorratsschädlicher Arthropoden mit Räubern und Parasitoiden – Sammelbericht und Bibliographie [Biological control of stored product arthropods with predators and parasitoids – a review and bibliography]. In: Reichmuth, Ch. (ed.), Wichtige Arbeitsschwerpunkte im Vorratsschutz, Mitteilungen der Biologischen Bundesanstalt für Land- und Forstwirtschaft, Heft 342, Parey Buchverlag Berlin, 341 pp., online: www.jki.bund.de, 85-189.

Schöller, M. 2010. Biological control of stored product insects in commodities, food processing facilities and museums. In: Cavalho, M. O., Fields, P. G., Adler, C. S., Arthur, F. H., Athanassiou, C. G., Campbell, J. F., Fleurat-Lessard, F., Flin, P. W., Hodges, R. J., Isikber, A. A., Navarro, S., Noyes, R. T., Riudavets, J., Sinha, K. K., Thorpe, G. R., Timlick, B. H., Trematerra, P., White, N. D. G. (eds.), Proceedings of the 10th International Working Conference on Stored Product Protection, 27 June – 2 July 2010 in Estoril, Portugal, pdf online: www.jki.bund.de, Julius-Kühn-Archiv 425 (1), 596-606.

Schöller, M. 2013. Checkliste der mit Vorräten assoziierten Insekten Deutschlands [Checklist of stored product insects in Germany]. Journal für Kulturpflanzen 65, 192-203.

Schöller, M., Prozell, S. 2014. Stored-product insects and their natural enemies in Germany: a species-inventory. In: Athanassiou et al., 27-34.

Schöller, M., Prozell, S., Al-Kirshi, A.-G., Reichmuth, Ch. 1997: Towards biological control as a major component of integrated pest management in stored product protection. Journal of Stored Products Research 33, 81-97.

Sekhon, R. K., Schilling, M. W., Phillips, T. W., Hasan, M. M., Aikens, M. J., Mikel, W. B. 2009a. Chemical composition of dry cured hams fumigated with carbon dioxide. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emission Reduction, 10-13 November in San Diego, CA, MBAO conference, www.mbao.org, 58-1 – 58-3.

Sekhon, R. K., Schilling, M. W., Phillips, T. W., Hasan, M. M., Aikens, M. J, Mikel, W. B. 2009b. Chemical composition of dry cured hams fumigated with phosphine. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emission Reduction, 10-13 November in San Diego, CA, MBAO conference, www.mbao.org, 59-1 – 59-3.

Sekhon, R. K., Schilling, M. W., Phillips, T. W., Hasan, M. M., Aikens, M. J. Mikel, W. B. 2010a. Sulfuryl fluoride fumigation effects on the safety, volatile composition, and sensory quality of dry cured ham. Meat Science 84, 505-511.

Sekhon, R. K., Schilling, M. W., Phillips, T. W., Hasan, M. M., Aikens, M. J., Nannapaneni, R., Mikel, W. B. 2010b. Effects of carbon dioxide and ozone treatments on the volatile composition and sensory quality of dry cured ham. Journal of Food Science 75, 452-458.

Sekhon, R. K., Schilling, M. W., Phillips, T. W., Hasan, M. M., Aikens, M. J., Corzo, A. Mikel, W. B. 2010c. Effects of phosphine and methyl bromide fumigation on the volatile flavor profile and sensory quality of dry cured ham. Meat Science 86, 411-417.

Sen, F., Aksoy, U., Tan, G. 2012a. Determining effect of sulfuryl fluoride fumigation on dried aprocots, raisins, and hazelnuts quality. Navarro et al., 2012a, 315-320.

Sen, F., Meyvaci, K. B., Turanli, F., Aksoy, U. 2010. Effects of short term controlled atmosphere treatment at elevated temperature on dried fig fruit. Journal of stored Products Research 46, 28-33.

Sen, F., Meyvaci, K. B., Turanli, F., Aksoy, U. 2012b. Influence of controlled atmosphere treatment on storage pests and qualöity of sun-dried fig fruits. Navarro et al., 2012a, 517-522.

Shi, M., Collins, P.J., Ridsdill-Smith, J., Renton, M. 2012. Individual-based modelling of the efficacy of fumigation tactics to control lesser grain borer (*Rhyzopertha dominica*) in stored grain. Journal of stored Products Research 51, 23-32.

Son, Y., Chon, I, Neven, L., Moon, Y., Cho, D., Kim, Y. 2012. Controlled atmosphere and temperature treatment systems to disinfest peach fruit moth, *Carposina sasakii* Matsumura (Lepidoptera: Carposinidae) on apples. Navarro et al., 2012a, 279.

Sotirouadas, V. 2012. Controlled atmospheres: Low-oxygen disinfestation of post harvest commodities in chambers and silos in Greece. Navarro et al., 2012a, 466-470.

Steidle, J. L. M., Niedermayer, S. 2013. Was Professor Hase noch nicht wußte: Biologische Bekämpfung von Vorratsschädlingen mit der Lagererzwepe: Vergangenheit, Gegenwart und Zukunft [Biological control of stored product pests using the parasitoid *Lariophagus distinguendus*: Past, presence and future]. (online: www.JKI.de), Journal für Kulturpflanzen 65, 123-126.

Subramaniam, B., Hulasare, R., Brijwani, M., Leitman, M. 2012. Effectiveness of heat treatments against *Tribolium castaneum* life stages in two commercial food-processing facilities. Navarro et al., 2012a, 281-290.

Tado, C. J. M., Gummert, M. 2012. Status and prospects of hermetic storage of rice seeds in the Philippines. In: Navarro et al., 2012a, 459-465.

Tao, Z, Shiwei, L., Yanyu, L., Yang, C., Guangtao, L., Yongkui, C., Zihai, Z. 2012. Mortality of four stages of *Lasioderma serricorne* (Fabricius) exposed to low oxygen. In: Navarro et al., 2012a, 17-25.

Tapondjou, A. L. 2014. Phytochemicals and semio-chemical use in integrated protection of stored products programs. In: Athanassiou et al., 83-97.

TEAP 2010. May 2010 Progress Report. Vol. 2, Chapter 8: Decision XXI/10 Quarantine and Pre-Shipment Report. UNEP: Nairobi, Kenya, online: ozone.unep.org, 295 pp, 89-158.

TEAP 2010. Report of the Technology and Economic Assessment Panel, May 2010 - Volume 2 Progress Report. UNEP, Nairobi, Kenya, online: ozone.unep.org, 279 pp.

TEAP 2011. Report of the Technology and Economic Assessment Panel, May 2011 - Volume 2 Progress Report. UNEP, Nairobi, Kenya, online: ozone.unep.org.

TEAP 2012. May 2012 Progress Report. Chapter 10: Quarantine and Pre-Shipment uses of Methyl Bromide – Response to Decision XXIII/5. UNEP, Nairobi, Kenya, online: ozone.unep.org, 267 pp, 164-216.

Thalavaisundraram, S., Roynon, J. 2012. Penetration capacity of VAPORMATE™ TM into commercially plastic wrapped cardboard boxes filled with sultanas for controlling stored product pests. In: Navarro et al., 2012a, 384-388.

Thoms, E., Annetts, R., Williamson, P., Cornally, D., Bishop, S., Ryan, R. 2012. Evaluation of PROFUME® gas fumigant (sulfurylfluoride) in ambient air adjacent to a bulk grain storage in Australia. In: Navarro et al., 236-240.

Tsai, W.-T., Mason, L. J., Chayaprasert, W., Maier, D. E., Ileleji, K. E. 2011. Investigation of fumigant efficacy in flour mills under real-world fumigation conditions. Journal of stored Products Research 47, 179-184.

Tumambing, J., Depalo, M., Garnier, J. P., Mallari, R. 2012a. ECO$_2$FUME and VAPORPH$_3$PHOS phosphine fumigants – Global application updates. In: Navarro et al., 2012a, 363-373.

Tumambing, J., Mallari, R., Widayanti, S., Hararap, I. S., Salazar, G. 2012b. Phosphine fumigation protocols using ECO$_2$FUME® for complete control of strongly resistant cigarette beetle, *Lasioderma serricorne*, in Indonesia. In: Navarro et al., 2012a, 624-632.

Ulrichs, Ch., Mewis, I. 2013. Nanostrukturierte Silikate: Insektizide Wirkung und neue Entwicklungen [Nanostructured silicas – insecticidal effects and new developments]. (online: www.JKI.de), Journal für Kulturpflanzen 65, 118-122.

Vacquer, B., Lethuillier, L., Brunel, M., Fraterno, R., Fleurat-Lessard, F. 2014. First application in France of heat disinfestation of a large wheat mill. In: Athanassiou, Ch. G. et al., 243-251.

Vital, P. S. R. V. S., Roy, S., Modak, A., Venkat, P. S. R. A., Vegi, V. R., Ramana, M. R. S. V., Rajeshakar, R. 2012. Post fumigation product management: Hygiene and infestation management in leaf operations (HIMILO): An IPM system and on-line quality audit to protect fumigated tobacco stocks for long periods from cigarette beetle *Lasioderma seccicorne*. In: Navarro et al., 2012a, 738-739.

Wakil, W., Riasat, T., Saeed, N., Ashraf, M., Yasin, M. 2012. Fumigant activity of some essential oils aginst four major insect pests of stored grain. In: Navarro et al., 2012a, 389-395.

Walse, S. 2009. Ovicidal efficacy of sulfury fluoride to stored-product pests of dried fruit. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emission Reduction, 9 – 12 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 60-1 - 60-2.

Walse, S. 2012. Personal communication. January 2013

Wang, D., Hui, L. 2012. Comparative mortality of *Liposcelis entomophila* (Enderlein) to ethyl formate in empty bins. In: Navarro et al., 2012a, 416-420.

Wang, D., Tang, J., Johnson, J. A., Cavalieri, R. P. 2013. Heating uniformity and differential heating of insects in almonds associated with radio frequency. Journal of stored Products Research 55, 15-20

Widayanti, S., Harahap, I. S., Sunjaya. 2012. Efficacy and registration status of ECO$_2$FUME 2 LG against *Tribolium castaneum* (Herbst), *Sitophilus zeamais* Motschulsky and *Oryzaephilus surinamensis* (L.) on milled rice in Inonesia. In: Navarro et al., 2012a, 411-415.

Williams, L.H., Sprenkel, R.J. 1990. Ovicidal activity of sulfuryl fluoride to anobiid and lyctid beetle eggs of various ages. Journal of entomological Science 25, 366-375.

Williams, R. E. 2009. Control of carob moth (*Ectomyelosis ceratonia*) in fresh dates fumigated with ProFume®. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emission Reduction, 9-12 November in San Diego, CA, USA, MBAO conference, www.mbao.org, 63-1.

Williams, R., Thoms, E., 2008. ProFume® update: Post-harvest commercial acceptance and performance in the US. In: Obenauf, G. L. (ed.), Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emission Reduction, 11-14 November in Orlando Fl, CA, USA, MBAO conference, www.mbao.org, 84-1 – 84-2.

Wong, F., Castañé, C., Riudavets, Y. 2012. Lethal effect of CO_2 modified atmospheres on eggs of different age of two bruchid species. In: Navarro et al., 2012a, 26-31.

Xiaoping, Y., Yuxin, Ch., Guaogan, X., Juan, Z., Jiade, S., Guangli, Sh, Shengjie, J., Jialiang, W. 2008. Mortality of three stored product pests exposed to sulfuryl fluoride in laboratory and field tests. In: Daolin, G. et al. (eds.), Proceedings of the 8th International conference on Controlled Atmosphere and Fumigation, 21-26 September 2008, Chendu, Sichuan Publishing House of Science and Technology, Chengdu, 191-195.

Xin, N., Ren, Y. L., Forrester, R. I., Xue Ming, Mahon, D. 2008. Toxicity of ethyl formate to adult *Sitophilus oryzae* (L.), *Tribolium castaneum* (Herbst) and *Rhyzopertha dominica* (F.). Journal of stored Products Research 44, 241-256.

Yamada, K., Shukuya, T., Ogawa, N., Misumi, T. 2012. Mortality test of ethyl formate fumigation for leaf miner (*Liriomyza sativae*, *Liriomyza trifolii*) and Spider Mite (*Tetranychus cinnabarinus*, *Tetranychus kanzawai*). Res. Bull. Pl. Prot. Japan 48, 13□17 .

Yongxue, D., Wang, J., Dou, W., Yang, Z., Jiang, T.-K. 2010. Fumigation activities of ethyl formate on different strains of *Liposcelis bostrychophila*. In: Proceedings of the 10th International Working Conference on Stored Product Protection. Julius-Kühn-Archiv, 459-463.

Yongxue, D., Wang, J., Li, J. 2008. Toxicity of ethyl formate of adults of *Liposcelis entomophila*. In: Proceedings of the 8th International Conference on Controlled Atmosphere and Fumigation in Stored Products, 21-26 September 2008, Chendu, P.R.China, Sichuan Publishing House of Science and Technology, Chengdu, 212-238.

Yongxue, D., Wang, J., Li, J. 2008. Toxicity of ethyl formate of adults of *Liposcelis entomophila*. In: Daolin, G., Navarro, S., Jian, Y., Chang, T., Zuxun. J., Yue, L., Yang, L., Haipeng, W. (eds.), Proceedings of the 8th International Conference on Controlled Atmosphere and Fumigation in Stored Products, 21-26 September 2008 in Chengdu, China. Sichuan Publishing Group, Sichuan Publishing House of Science and Technology, Chengdu, China, 212-238.

Zakladnoy, G., Abdiushev, M., Soskin, M. 2012. Phosphine recirculation system in a metal bin. In: Navarro et al., 2012a, 603-606.

Zeng, L., Lao, Ch., Guo, Ch, Xian, Q, Zhen, M. 2012. Effects of controlled atmospheres for insect control and quality preservation of milled rice using three ways to reduce oxygen. In: Navarro et al., 2012a, 501-508.

Zhao, Y., Phillips, T. W., Abbar, S., Mikel, W. B., Schilling, M. W. 2012a. Effects of various food-grade coatings on mite mortality and sensory quality of dry cured ham. In: Obenauf, G. (ed.), Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 6-8 November in Orlando, FL, USA, MBAO conference, www.mbao.org, 77-1 - 77-3.

Zhao. Y., Phillips, T. W., Aikins, M. J., Mikel, W. B., Schilling. M. W. 2012b. Sensory evaluation and pest mortality of dry cured ham fumigated with phosphine in a simulated ham aging house. In: Obenauf, G. (ed.), Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 6-8 November in Orlando, FL, USA, MBAO conference, www.mbao.org, 78-1 – 78-3.

Ziaee, M., Moharrmipour, S. 2012. Fumigant toxicity of *Carum copticum* essential oil against *Sitophilus granarius*. In: Navarro et al., 2012a, 96-100.

7

Chapter 7. Factors assisting the methyl bromide phaseout in Article 5 countries and remaining challenges

7.1. Introduction

As per the mandate of Decision XXIII/12, this chapter updates the progress made in phasing out controlled uses of methyl bromide in Article 5 countries. In view of the phase-out date of 1st January 2015 already in place, it addresses challenges and factors that could potentially put the sustainability of the phase-out at risk. The major technologies implemented and the factors that have assisted MB phase-out in MLF projects and other efforts to replace MB are discussed.

By end of 2013 (the last date for which official data were available at the time of writing this report), about 86% of the controlled uses of MB in Article 5 Parties had been phased out. This was primarily achieved through MLF-funded projects implemented by the agencies of the Montreal Protocol, and has taken place at different rates in different regions. This chapter includes a list of the main types and objectives of such projects together with the main alternatives successfully replacing MB in different countries and regions. Detailed information on consumption trends in Article 5 countries including the key sectors using MB can be found in Chapter 3 of this Assessment Report.

Various information sources were used in compiling this chapter: the Data Access Centre of the Ozone Secretariat (accessed December 2014/ January 2015), the project database of the MLF Secretariat (accessed December 2014), MLF project reports submitted by governments, information provided by national specialists and implementing agencies, and published papers listed in section 7.3.

7.2. Methyl Bromide phase-out in Article 5 regions overview

Although overall MB phase-out has progressed substantially in all A-5 regions, this has occurred at different speeds (see section 3.5.1 and Fig 7-1 of this report). The phase-out situation up to 2013 (as reported to the Ozone Secretariat) is presented below in Table 7-1. This will however change substantially for 2014 given the phase-out deadline of 1st January 2015. Mexico, for example, the largest A5 consumer in 2013, has already informed that its MB consumption for controlled uses in 2014 was zero.

The pace at which MB has been successfully replaced seems to be in direct relation to the consuming sectors involved, and particular circumstances present in individual countries, including developments concerning new crops (with challenging requirements, pests or diseases) or large expansion of existing crops where newcomers to such sectors (growers and other stakeholders) are not sufficiently trained on the use of alternatives. Regulatory issues (e.g. registration of alternatives) and political issues (e.g. difficulties in restricting MB imports and tracking their final use) may also contribute to this (UNEP, 2014).

TABLE 7-1. REPORTED MB CONSUMPTION FOR CONTROLLED USES IN A-5 REGIONS IN 2013 AND PHASE-OUT ACHIEVED WITH RESPECT TO REGIONAL BASELINES

Region	Baseline	2013 consumption (metric tonnes)	% phase-out (as per regional baseline)
Africa*	4473	340	92%
Asia-Pacific	4104	294	93%
Eastern Europe	900	0	100%
Latin America & Caribbean	6391	1643	74%
TOTAL	**15,866**	**2277**	**86%**

Source: Ozone Secretariat Database, January 2015

* These figures have changed since previous reports due to corrected consumption reports from South Africa

7.3. MLF projects in Article 5 Countries

The Multilateral Fund (MLF) was established under Article 10 of the Montreal Protocol to provide financial assistance to Article 5 countries for phasing out ODS including MB. Assistance for MB issues was provided as early as 1994 and projects to assess the feasibility of alternatives became eligible for support from the Fund in 1995. In 1997, the Executive Committee of the MLF convened a group of experts to develop a strategy and guidelines for MB phase-out projects, which were adopted in 1998, and revised in 2000. In essence, this work helped outline the priority sectors where MB needed to be replaced in Article 5 countries, established guidelines for investment and non-investment projects, and recommended approaches to project development. These inputs were instrumental for the MLF's four implementing agencies (UNEP, UNDP, UNIDO and the World Bank), to prepare and implement the different kinds of projects in conjunction with interested Parties (UNEP, 2014). Project preparation and implementation followed a logical approach, with particular project types targeted at specific goals, as described in Table 2.

In addition to MLF efforts, a number of MB projects have been funded from other sources, by Article 5 countries themselves - for example China – or by the Global Environment Facility (GEF), or bilateral assistance for example from the governments of Australia, Germany (GTZ, now GIZ), Italy, Canada and Spain. In some countries farmers or exporters associations or private enterprises have also financed experiments to identify or adapt alternatives to MB; examples include those in Morocco, Egypt, Jordan, Lebanon and Kenya. In all projects, costs are shared with a local counterpart institution and key stakeholders, for example growers or their trade organizations.

MLF projects, together with voluntary efforts from growers and users, have made a major contribution to the MB reductions described in Chapter 3. A description of the main types of MLF projects is included in Table 7-2 below together with an overview of the main alternatives selected and adopted in Article 5 countries.

Technical descriptions and other information on alternative technologies are not covered in this chapter but are provided in Chapters 5 (alternatives for soil treatments) and 6 (alternatives for commodity and structural treatments).

TABLE 7-2. TYPES OF MB PROJECTS DEVELOPED WITH ASSISTANCE FROM THE MLF, GOALS AND ACHIEVEMENTS

Project Type	Goals and achievements
Technical Assistance and Training	Play a key role in improving data collection on MB consumption, integrating the NOUs to phase-out activities and developing or strengthening policy packages aimed at sustaining the phase-out achieved. Normally not aimed at replacing specific quantities of MB but this has on occasion been achieved
Demonstration	Instrumental in raising awareness on MB phase-out, identifying consuming sectors and evaluating suitability of alternatives. Generally not aimed at phasing-out a particular amount of MB. Served to identify problems hindering adoption of alternatives (inappropriate involvement of key stakeholders, lack of participation from NOUs, alternatives being inappropriate for specific sector).
Investment	Generally implemented once successful alternatives have been identified during the demonstration stage. Carry agreement from the country to phase out MB consumption for controlled uses by a given deadline, and to support sustainability of the phase-out achieved with a policy package aimed at banning future MB use for controlled uses.

Source: UNEP, 2014

7.3.1. Number and cost of MLF projects

By December 2014 the MLF had approved a total of 398 projects in more than 80 Article 5 countries, with an approved expenditure of approximately USD $137 million (MLF, pers comm 2015). This included all types of MB-related activities: demonstration projects, technical assistance, training, project preparation, workshops, awareness raising and MB phase-out projects. The latter are also called investment projects, multi-year projects or national phase-out plans and are normally geared at full phase-out before or at the 2015 deadline.

The figures below provide data on MLF projects approved between 1992 and December 2014 (MLF, 2014):

- **Demonstration projects** – 44 were approved since 1992 (2 were cancelled).
- **Technical assistance -** 74 projects concerning information and awareness-raising activities such as workshops, technical assistance, information exchange on MB phase-out and alternatives, policy development and various other activities (one cancelled).
- **Training** – 21 projects
- **Project preparation** – 130 initiatives for the preparation of new projects, including the collection of data on MB uses (11 cancelled); and
- **Investment or MB phase-out projects** – 129 projects. This category is the one showing the largest increase since 2006.

MLF projects approved by December 2013 were scheduled to eliminate a total of 13,939 metric tonnes of MB in Article 5 countries (MLF, 2015). The total phase-out achieved by MLF projects by December 2013 was 12,165 tonnes (Table 7-3), which is 87% of the total due to be phased out by the projects, a figure which is higher than in previous years.

TABLE 7-3: IMPACT OF MLF MB PROJECTS APPROVED AS AT DECEMBER 2013

Project type	MB phaseout approved in projects (tonnes)	Phase-out achieved by December 2013 (tonnes)
Investment	13,403.7	11,425.5
Demonstration	38.7	38.7
Technical assistance	486.3	690.7*
Training	10.5	10.5
Total	**13,939.2**	**12,165.4**

Source: MLF Secretariat, January 2015

* Technical Assistance projects implemented in Yemen, Syria and Mexico achieved greater phase-out than planned.

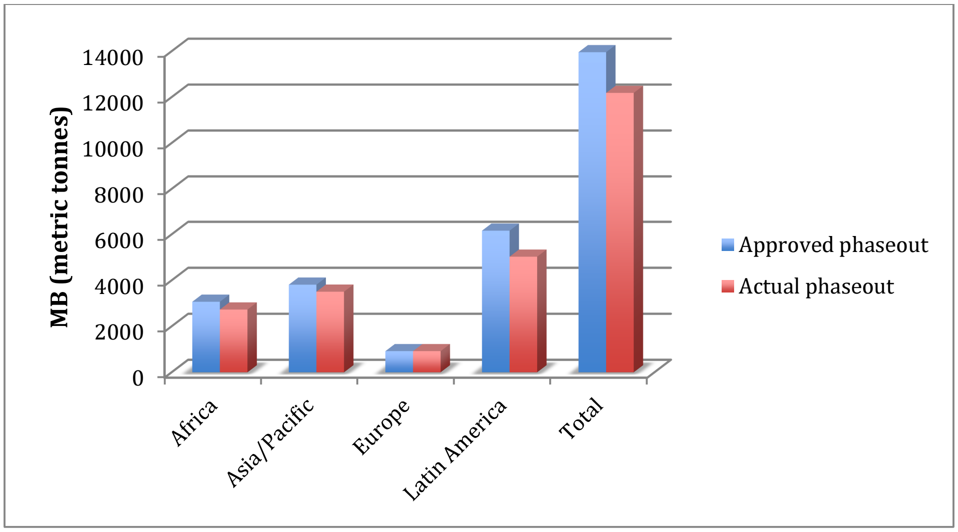
Table 7-4 and Fig.7-1 present an analysis of the phase-out achieved through the different types of projects in the Article 5 regions. Please note that demonstration and technical assistance projects are not tied to specific phase-out but in some cases have replaced MB use.

TABLE 7-4. PHASE OUT ACHIEVED PER REGION AND APPROVED FUNDS FOR PROJECTS

Region	No. Projects	Impact (metric tonnes)	Phased out (metric tonnes)	US$ approved
Africa	108	3,065	2,727 (89%)	32,765,636
Asia and the Pacific	101	3,812	3,506 (92%)	36,509,047
Europe	33	919	919 (100%)	9,675,984
Latin America and the Caribbean	122	6,159	5,028 (82%)	54,367,588
Africa (regional)	9	2.5	2.5	1,896,068
Asia and the Pacific (regional)	3	-	-	210,505
Latin America and the Caribbean (regional)	7	-	-	702,761
Global	15	-	-	1,086,072
Total	398	13,957.5	12,182.5 (87%)	137,213,660

Source: MLF, January 2015

FIG. 7-1. AMOUNTS OF METHYL BROMIDE PHASED-OUT BY REGION, THROUGH MLF PROJECTS AS AT DECEMBER 2013



Source: MLF, January 2015

7.3.2. Demonstration projects

Demonstration projects were not intended to reduce or phase-out MB consumption, but rather at transferring technologies to Article 5 regions from countries that already used alternatives, evaluating and comparing performance and efficacy of successful alternatives (including yields, costs, etc.) under the specific circumstances found in Article 5 countries. The projects considered differences in agricultural practices, resource availability, climatic conditions and other relevant factors. Table 7-5 provides a summary of demonstration projects implemented in the past. Detailed information on these projects can be found in the MBTOC 2002, 2006 and 2010 Assessment Reports (MBTOC 2002, 2007, 2011).

These projects evaluated a wide range of chemical and non-chemical alternatives, in diverse situations, climates, soil types and cropping systems, and involved many different types of MB users, ranging from small producers with less than 0.5 ha, to medium and large producers, who produced under low, medium and higher levels of technical sophistication (which does not necessarily correlate with size of operation).

With very few exceptions, demonstration projects enabled the identification of suitable alternatives for all key sectors using MB. They also helped highlight possible barriers and constraints to commercial adoption of alternatives, which were taken into account when implementing investment projects.

TABLE 7-5. DEMONSTRATION PROJECTS FUNDED VIA THE MLF AND BILATERAL AGREEMENTS AND KEY SECTORS ADDRESSED

Region	Country	Crops covered in demonstration projects (soil fumigation)	Postharvest sectors covered
Latin America and Caribbean	Argentina	Tobacco, protected vegetables, tomato, flowers, strawberry	Cotton and citrus
	Brazil	Tobacco	
	Chile	Tomato, pepper	Commodities
	Colombia	Banana	
	Costa Rica	Melon, cut flowers,	
	Cuba	Tobacco	
	Dominican Republic	Tomato, melon, tobacco, flowers	
	Ecuador	Flowers	
	Guatemala	Broccoli, melon, tobacco, tomato, flowers	
	Jamaica		Tobacco, stored commodities, flour mills
	Mexico	Tomato, strawberry fruit, melon, flowers, tobacco	Structures (warehouses and flourmills)
	Uruguay	Cucumber, pepper, tomato seedbeds, tobacco, nurseries	
Africa	Algeria		Dates
	Botswana	Tomatoes and cucurbits	
	Cameroon	Tobacco	
	Egypt	Strawberry, tomato, cucurbits	Stored grain
	Kenya	Flowers	Stored grain
	Morocco	Tomato, cucurbits, strawberry fruit, flowers, bananas, greenbeans	
	Senegal		Peanut seed
	Tunisia		Dates
	Zimbabwe	Tobacco, cut flowers	Stored grain
Asia	China	Tobacco, tomatoes, cucumber, strawberries, ginseng, ginger	Stored grain
	Indonesia		Stored products: milled rice, wood products
	Jordan	Cucumber, tomato, other soil uses	
	Lebanon	Tomato, cucurbits, eggplant, strawberry fruit, strawberry runners	
	Malaysia		Stored timber
	Philippines	Banana, other soil uses	Flour mills, stored grain
	Sri Lanka	Tea plantations	
	Syria	Post-harvest and horticulture	
	Thailand		Stored grain: rice, maize, tapioca, feed grains, pulses
	Vietnam	Flowers, vegetables	Stored grain, rice, silos, timber
Eastern Europe / CEIT	Croatia	Tobacco	
	Macedonia	Tobacco, horticultural seedlings, vegetables	
	CEIT region	Tomato, cabbage, pepper, celeriac, strawberry	
	Turkey	Tomato, cucumber, flowers, strawberry, pepper, eggplant	

7.3.3. Phase-out projects

Phase-out projects (also called investment projects, multi-year agreements, national phase-out plans or sector plans) aimed to replace MB use by assisting the commercial adoption of alternatives that have been identified as technically and economically feasible for a particular country and crop situation, either as a result of demonstration projects carried out previously or from experience derived from similar sectors, regions and circumstances. They normally included schedules or timetables for national MB reductions that lead to phase-out earlier or by 2015.

These projects have normally provided assistance to growers and other MB users in the adoption of MB alternatives, for example in the form of equipment and materials, by training large numbers of direct users and extension staff on the effective application of alternative methods, and/or by providing technical expertise. The projects also helped with the development and implementation of policy measures to restrict MB after its phase-out, and facilitating registration of alternatives when necessary. Such policy measures also help ensure that MB imported for QPS (exempted) uses does not end up being used in controlled applications.

Phase-out projects have particularly addressed those sectors where MB use was most relevant in Article 5 regions: strawberries (fruit and runners), cucurbits, cut flowers and ornamental plants, tobacco seedlings, tomato, pepper and eggplant, green beans, ginger, bananas and fruit tree production. The majority of projects in the postharvest sector have been for stored grain and dried foodstuffs, and some have included structures such as warehouses and flourmills.

The projects showed that very large MB reductions are feasible over periods of 4 – 5 years, especially in cases where governments and MB users make constructive efforts to register, transfer and adopt existing alternatives.

7.3.4. Alternatives chosen in investment projects

In general terms, two broad categories of alternatives to MB can be considered: 1) In-kind alternatives or systems, consisting of replacing MB with another fumigant having similar or comparable effects (e.g. alternative fumigants) and 2) not-in-kind systems, which work best when implemented within an integrated approach and do not provide a direct, one-to-one replacement (see Table 7-6).

The fact that MB uses should not ideally be replaced by one in-kind alternative was highlighted in past MBTOC Assessment reports (1994, 1998, 2002, 2007, 2011) and was confirmed in MLF projects. This often meant that growers and other stakeholders had to change their approach to production and even make changes in process management, mostly related to the implementation of IPM practices but also time management as some alternatives require longer exposure times than MB. Reluctance to change has often been cited as one of the major reasons delaying adoption of alternatives, even above economic concerns.

Projects conducted in Article 5 countries have demonstrated that a similar range of alternatives as those of non-Article 5 countries can be successfully adopted. Differences in costs, logistics and resource availability can lead to a preference for different alternatives in Article 5 compared to non-Article 5 countries.

TABLE 7-6. MAIN CATEGORIES OF ALTERNATIVES TO METHYL BROMIDE

Alternatives	Soils	Post-harvest	Comments
In-kind	Soil fumigants (1,3-D, Pic, metham sodium, dazomet, metham potassium, DMDS	Phosphine, sulfuryl fluoride, HCN, EDN	Meant to perform as direct replacements to MB. May not be sustainable in time due to regulatory issues
Not in-kind	Grafting, substrates, floating trays, steam, compost, biocontrol, solarisation, resistant cultivars, crop rotation and inter-cropping, organic amendments biofumigation	Heat (full and spot treatments), cold, vacuum, pheromones, contact insecticides	Work best and give the most sustainable result when combined, within an IPM strategy

Table 7-7 lists the main alternatives adopted by some Article 5 countries by region and the degree to which they have currently displaced MB use (many have phased out MB completely). For a detailed description of alternatives please refer to Chapters 5 and 6 of this Assessment Report.

TABLE 7-7. TECHNOLOGIES ADOPTED IN MB PHASEOUT PROJECTS, BY REGION

Region	Country	Soil technologies selected	Postharvest technologies selected	% MB replaced by 2013*
Latin America and Caribbean	Argentina	Chemicals (1,3-D/Pic, MS, DMDS), steam, floating trays, grafting		39% of baseline
	Bolivia	Steam, substrates		Phased out
	Brazil	Floating trays, substrates, metham sodium, steam, solarisation (solar collector)		Phased out
	Chile	1,3-D/pic, steam, steam + Trichoderma, metham (rotary-spading injection), methyl iodide		22% of baseline
	Costa Rica	1,3-D/pic, metham, solarisation, biocontrols, steam		Phased out
	Cuba	Floating trays. Steam, grafting, biocontrols	Phosphine + CO_2 and heating, sulfuryl fluoride	Phased out
	Dominican Rep.	Floating trays, solarisation, metham sodium, steam, substrates		Phased out
	Ecuador	Substrates, chemicals, biofumigation		Phased out
	Guatemala	Chemicals, grafting, biocontrols		60% of baseline
	Honduras	Chemicals, floating trays, grafting, biocontrols		Phased out

Region	Country	Soil technologies selected	Postharvest technologies selected	% MB replaced by 2013*
	Mexico	Grafting, chemicals, IPM, steam, solarisation	Phosphine + CO_2	71% of baseline
	Peru	Steam, floating trays, solarisation, biocontrols, biofumigation		Phased out
	Uruguay	Solarisation + chemicals (1,3-D/Pic, MI, MS, DMDS), biofumigation, steam		Phased out
Africa	Congo	Metham, IPM		Phased out
	Egypt	Substrates, steam, biofumigation, grafting	Phosphine, PH_3 + CO_2	77% of baseline
	Kenya	Metham (rotary-spading injection), substrates, steam, grafting, IPM	Phosphine, PH_3 + CO_2	Phased out
	Malawi	Floating trays, chemicals (metham sodium, dazomet)		Phased out
	Morocco	1,3-D/pic, metham, grafting, solarisation + chemicals, steam, substrates, compost		Phased out
	Senegal		Phosphine, (tablets of metallic phosphide) IPM,	Phased out
	Sudan		Phosphine, IPM	77% of baseline
	Uganda	Metham (rotary-spading injection), steam, substrates		Phased out
	Zimbabwe	Steam, IPM, floating trays	Phosphine	Phased out
Asia	China	Metham sodium, grafting, chloropicrin, 1,3-D, limited biocontrol	Phosphine	91% of baseline
	Indonesia		Phosphine, IPM	Phased out
	Iran	Steam, solarisation, with IPM	Phosphine, IPM, Metallic phosphides	99% of baseline
	Jordan	Solarisation, grafted plants, chemicals, biocontrols, others		98% of baseline
	Lebanon	1,3-D,, 1,3-D/ Pic, metham sodium, solarisation, solarisation + reduced doses of chemicals, grafting, crop rotation, biofumigation, floating trays		Phased out
	Libya	Solarisation + chemicals (low doses), substrates, grafting.		Phased out
	Philippines		Phosphine + CO_2 IPM	Phased-out
	Syria		Phosphine + CO_2 IPM	Phased out
	Thailand		Phosphine, CO_2, aluminium phosphide, IPM, sulfuryl fluoride, controlled atmospheres	Phased out

Region	Country	Soil technologies selected	Postharvest technologies selected	% MB replaced by 2013*
	Turkey	Grafting, metham sodium, 1,3-D, 1,3-D/Pic, solarisation, substrates, grafting, resistant varieties, steam (limited), dazomet	CO_2 and magnesium phosphide	Phased out
	Tunisia*		Phosphine + CO_2	20% of baseline
	Vietnam		IPM, phosphine, CO_2, sulfuryl fluoride, controlled atmospheres	63% of baseline
Eastern Europe / CEIT	Bosnia & Herzegovina	Floating trays, solarisation, biofumigation		Phased out
	Bulgaria [a]	Metham (rotary-spading injection), dazomet		Phased out
	Croatia	Floating trays		Phased out
	Hungary	Metham (rotary-spading injection), dazomet		Phased out
	Macedonia	Floating trays, solarisation+biofumigation		Phased out
	Poland [a]	Metham (rotary-spading injection), dazomet, steam		Phased out
	Romania	Chemicals, grafting, solarisation + 1,3-D/ Pic, metham sodium		Phased out

Sources: UNIDO, UNDP, World Bank, national experts and Desk Studies on Methyl Bromide Projects, MLF, 2005b, MLF, 2007, Evaluation of MB projects in Africa MLF, 2012. Data Access Centre of Ozone Secretariat, January 2015.

[a] GEF regional project in CEIT countries

* Consumption in Tunisia has been exempted as falling under Dec XV/12, but this exemption is now under review as alternatives for high moisture dates have become available (see Chapter 6 of this report)

7.3.5. Crop specific technology choices in A5 countries

Detailed descriptions of the main alternatives selected for the key sectors using MB is in A5 countries can be found in Chapters 5 and 6. Table 7-8 below presents a summary of alternatives that have successfully replaced MB in the key sectors previously using this fumigant. It is once again noted that most often, the combination of these alternatives within an IPM approach gives the best results.

TABLE 7-8. MAIN ALTERNATIVES ADOPTED FOR KEY SECTORS PREVIOUSLY USING MB IN ARTICLE 5 PARTIES

Sector	Main alternatives	Examples of countries where adopted
SOILS		
Strawberry fruit	1,3-D/ Pic, Pic alone, metham potassium, substrates	Argentina, Mexico, China, Egypt, Morocco, Turkey, Chile, China
Strawberry runners	1,3-D/ Pic, metham sodium, steam, solarisation	Argentina, Mexico, Lebanon, Turkey, Chile
Cucurbits	Grafting, solarisation, metham sodium, biocontrols, resistant cultivars	Mexico, Morocco, Turkey, Costa Rica, Guatemala, Honduras, China
Tomato, pepper, eggplant	Grafting, solarisation, 1,3-D/Pic, metham sodium, DMDS, substrates, compost, biocontrols, resistant cultivars	Turkey, Mexico, Argentina, Morocco, China
Cut flowers and ornamental crops	Substrates, steam, solarisation, biofumigation, chemicals (1,3-D/Pic, metham sodium)	Kenya, Ecuador, Uganda, Brazil, Mexico, Colombia, Argentina, Costa Rica, Dominican Republic
Nurseries	Substrates, steam+ biocontrols, 1,3-D/Pic	Chile, Brazil, Costa Rica, Colombia, Kenya, Argentina
Tobacco	Floating seed trays, dazomet, metham sodium	Argentina, Brazil, Zimbabwe, Malawi, Zambia, Cuba, Peru, Macedonia, Croatia
STRUCTURES AND COMMODITIES		
Grain, coffee, cocoa, rice, dried fruit, nuts and other foodstuffs	Phosphine, phosphine+CO_2, controlled atmospheres	Turkey, Sudan, Egypt, Kenya, Viet Nam, Thailand, China, Indonesia, Singapore
Flour mills, food processing premises	Heat, sulfuryl fluoride, IPM	Egypt, Thailand, Viet Nam, Jamaica

7.3.6. Lessons learned from projects

A review of 2013 consumption data (the last date for which officially reported consumption was available at the time of preparing this report) shows very significant progress in phasing out MB as the established phaseout deadline of 2015 approached.

The implementation of MLF projects has provided many useful experiences that can be summarised as follows:

- As controlled uses are phased out it has become increasingly important to document and characterise QPS uses more closely, to prevent ‘leakage’ to other uses, and to strengthen policy measures relating to MB use.
- Technically effective alternatives to MB have been found for virtually all pests, diseases and weeds, however a small number of sectors and situations still pose challenges, for example ginger in China and strawberry nurseries in Mexico.

- The cost and profitability of alternatives was found to be acceptable or comparable to MB in many projects. However it is desirable to make further efforts to reduce the costs of alternatives in some specific situations, to prevent users reverting to MB.
- While a number of projects have promoted alternatives that will be environmentally sustainable in the longer term (such as IPM and non-chemical approaches), some projects focussed primarily on chemical alternatives. Chemical treatments, particularly fumigants, are likely to face increasing regulatory restrictions worldwide in future.
- The capability to adapt to site-specific conditions is essential to the success of any alternative.
- Projects demonstrated that successfully evaluated alternatives can be adopted by large numbers of growers in developing countries in periods of 2-4 years within proactive projects. Also, activities related to demonstration projects led larger or more technically prepared growers to adopt alternatives at their own initiative.
- Involvement of an ample range of key stakeholders is essential to the success of a project or the phase out achieved.

7.4. Constraints on adoption and remaining challenges

Although technically feasible alternatives have been identified for virtually all uses of MB, it quickly became clear that each alternative system needed to be judged against the local situation and commercial environment. Various issues beyond the economic feasibility of alternatives impact the long-term sustainability of the proposed alternatives have been identified, for example:

- Market drivers - specific market windows requiring precise technical and business skills
- Consumer issues - preference for certain certification schemes or eco-labels
- Installed capacity - sufficient and economically feasible airfreight and/or cold storage
- Regulatory factors – registration and commercial of alternatives
- Sufficient consumption volume of a given input to develop a market and ensure availability of an alternative.

7.4.1. Challenges

Particular challenges or concerns, which could put at risk the sustainability of the phase-out achieved still remain, for example:

- **The continued, unrestricted supply of MB.** As long as no controls are in place, continuing, plentiful production of MB for allowable QPS purposes provides a base production capacity and scale for the industry that can keep MB prices at a level where it is still attractive for non-QPS users. This situation, often combined with well-funded promotional efforts for MB use, negatively impact the phase-out achieved. Initiatives taken by the Parties in previous years to evaluate the feasibility of adopting alternatives for QPS have shown that it is easily possible to replace a proportion of the MB used for this purpose.

- **Deviation of use**. Many A-5 countries have expressed concern over illegal trade and/or use, and in particular, the diversion of MB imported for QPS uses into controlled applications. Consumption for QPS has shown an upward trend in many A-5 countries over the last decade, and although increased trade could partly explain this, the difficulty in tracking actual final use of imported MB is often referred to.

- **Long-term viability of some alternatives**. Restrictions and bans on chemical alternatives as a result of environmental or health concerns may arise. Further, essential inputs for implementing some alternatives may become unavailable or too expensive. The switch to alternatives may allow for the more frequent presence of pests or diseases that were secondary in the past (or controlled to a very large extent with MB). Pest resistance to alternatives may also arise; this is for example a very real possibility when fumigating grain with phosphine, as already stated in this report.

- **Ensuring the continuity of project activities and achievements, once the projects are finished,** particularly training and awareness-raising. Creating linkages with other environmental/sustainability initiatives, promoting information exchange within productive sectors locally or at the regional level and others, can provide good options in this respect

In summary, willingness, commitment and a proactive approach are necessary for the successful adoption of alternatives and there are instances where reluctance to change appears to be the major barrier to successful adoption of alternatives.

A further constraint noted in Article 5 countries is the lack of registration of the more modern chemical alternatives (MLF 2005, ab, MLF 2012). This pertains for example in some countries to DMDS, 1,3-dichloropropene and its different formulations with chloropicrin as well as chloropicrin alone for soil uses, and sulfuryl fluoride in the postharvest sector. However, progress has occurred in many countries and these new chemicals or formulations are increasingly registered. In many countries, substantial MB reductions and phase-out have been achieved using non-chemical alternatives that do not require registration.

Large CUEs requested by some non-Article 5 countries in the past were reported to slow the progress of MLF projects and other phase-out initiatives in a number of Article 5 countries because confidence in alternatives and the feasibility of achieving MB reductions was impacted. Recent large reductions in CUNs however seem to have provided encouragement to Article 5 countries to complete their phase-out by the scheduled date. However some Article 5 countries have also requested CUNs as discussed in the following section.

7.5. Critical Use Nominations in Article 5 Parties

As per Montreal Protocol guidelines, Article 5 Parties can only use MB for controlled purposes under the Critical Use exemption as of 1st January 2015 and exemptions may be requested up to two years in advance. CUNs from four Article 5 Parties were received for the first time in 2014, for 2015 use. One Party later withdrew its request, leaving six CUNs all for the soil sectors, for strawberry and raspberry runners, ginger, tomatoes, peppers and strawberry fruit. MBTOC assessed these nominations and in some cases recommended adjustments for lower amounts on the basis of Decision IX/6.

In 2015, four Parties have again submitted CUNs, which will be assessed by MBTOC this year. More information on CUNs can be found in Chapter 3 of this report and in annual TEAP reports, plus the "Handbook for Critical Use Nominations" prepared by MBTOC (see http://ozone.unep.org/Assessment_Panels/TEAP/Reports/MBTOC/Handbook_CUN-version7-1-April_2013.pdf)

7.6. References

MBTOC (1995). 1994 Report of the Methyl Bromide Technical Options Committee: 1995 Assessment. UNEP: Nairobi. 304pp.

MBTOC (1998). Report of the Methyl Bromide Technical Options Committee. 1998 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi. 374pp.

MBTOC (2002). Report of the Methyl Bromide Technical Options Committee. 1998 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi. 451pp.

MBTOC (2007). Report of the Methyl Bromide Technical Options Committee. 1998 Assessment of Alternatives to Methyl Bromide. UNEP: Nairobi, 475 pp.

MLF. (2005a). Final Report on the evaluation of Methyl Bromide Projects. Montreal, 4-8 July 2005. Synthesis evaluation report (document UNEP/Ozl.Pro/ExCom/46/7)

MLF. (2005b) Evaluation of Methyl Bromide phase-out projects. Sub-sector reports and case studies. June, 2005. Reuben Ausher, Alejandro Valeiro, Marta Pizano, Jeurgen Boeye and Otto Mueck, Consultants

MLF (2007). Extended desk study on low volume methyl bromide projects. UNEP/OzL.Pro/ExCom/53/8 and Annexes 29 October 2007

MLF (2012) Evaluation of Methyl Bromide projects in Africa – Desk study. UNEP/OzL.Pro/ExCom/66/15. March, 2012. http://www.multilateralfund.org/66/English/1/6615.pdf

MLF (2014) Database of MLF projects, Multilateral Fund Secretariat, Montreal, accessed January 2015.

MLF, 2015, Personal communication. Multilateral Fund Secretariat for the Montreal Protocol

MPS (2005) Facts about MPS certification programme. MPS Codelist of crop protection agents. Milieu Programma Sierteelt (MPS), Honselersdijk.

Ozone Secretariat (2014) Data Access Centre. Database of ODS data submitted by Parties under Article 7, accessed December 2014.

UNEP (2014) Phasing out methyl bromide in developing countries: A success story and its callenges. Written by Marta Pizano. Uinted Nations Environment Programme UNEP/DTIE Paris 54 pp.

8

8. Methyl bromide emissions

8.1. Introduction

The phase out of MB under the Montreal Protocol has emphasised protecting the ozone layer from the destructive effects of MB through a schedule of progressive reductions in production and consumption of MB. The Parties have taken several explicit decisions calling for steps to minimise emissions of MB in applications where it is still used under Decisions which allow exemption from phaseout. These include the Critical Use Exemptions (Decision IX/6) and exemptions for QPS use (Article 2H, Decisions VII/5(c) and XI/13(7)). There is opportunity for Article 5 countries to adopt emission control technologies during progress towards full phase-out of MB in 2015 and for any 'Critical Uses' that may be granted by the Parties for subsequent use after 2015. As a consequence of several emission reduction technologies to date has been a reduction in dosage rates due to an increased efficiency of the use of MB. This chapter as with the past assessment reports continues to refine the best estimate of the level of emissions for the uses of MB as at 2013, the most recent year for which there is a good data set of consumption and use available. It also provides a summary of the impact of regulation of these emissions on the ozone layer, updates on developments in reducing emissions of MB, particularly the use of barrier films and reduced MB dosages for soils, and the potential for recapture, recycling and destruction for commodity and structural treatments.

8.2. Atmospheric Methyl Bromide

8.2.1. Global Sources and Emissions

Methyl bromide has both natural and anthropogenic sources. The current understanding of the global annual budget (sources and sinks) for MB is summarised in Table 8-1 and Figure 8-1. The current error estimates (range) for the 2012 MB budget are given in the caption to Table 8.1. The budget data continue to suggest that the global MB budget is not balanced. Current identified sinks exceed current identified sources by approximately 30 k tonnes (nearly 40% of identified sources). This imbalance has persisted from pre-Montreal Protocol phase-out (1995-1998) to recent times (2013). It is likely that the MB sinks are more accurately known than the sources. This implies that there may have been either large under reporting of MB production and consumption or that there are unidentified MB sources. Some of these may come from industrial processes, for example the production of purified tetraphthalic acid (PTA) or may be from unidentified natural sources.

The natural sources of MB are dominated by the oceans (about 30 k tonnes per year) and terrestrial plants (about 10 k tonnes per year). The MB sinks include chemical losses in the atmosphere (60 k tonnes per year), loss to the ocean and to soils (each about 30 k tonnes per year). In 2012 about half of MB emissions were anthropogenically-influenced and half were natural.

The ocean is the largest source of MB and the second largest sink. Resolving the current global budget imbalance requires a better understanding of the oceanic sources and sinks, industrial sources and natural vegetative sources of MB. This will require a more comprehensive set of MB observations in the marine boundary layer and in the ocean, and a representative survey of industrial, and vegetative emissions, particularly in the tropics, with better global coverage and year-round observations. This requires extensive and year-round shipboard, aircraft and surface observations and which are currently beyond the resources of the global MB observation community. Because of MB's relatively low concentration in the atmosphere, future satellite-borne instruments are unlikely to be able to address this 'data-poor' MB issue.

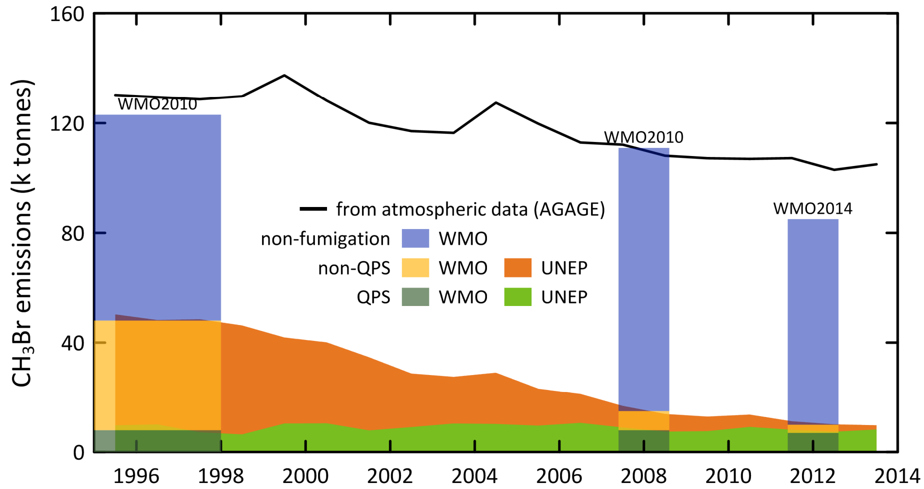
Australia is addressing this global lack of tropical observations of atmospheric MB by establishing a tropical atmospheric research facility at Gunn Point (12°S) in the Northern Territory and instigating continuous MB measurements in partnership with Cambridge University.

Historically, the largest anthropogenic source of MB emission is from fumigation of soils and commodities and structures, where about 50 k tonnes per year were emitted to the atmosphere between 1995 to 1998 from non-QPS MB use (85%: largely soil fumigation) and QPS use (15%: largely grain and wood products fumigation including QPS). As Montreal Protocol restrictions on the consumption of MB for non-QPS use have been implemented, this total fumigation source of emissions has reduced to about 10 k tonnes by 2012 (30% non-QPS, 70% QPS).The uncertainty of fumigations emissions is about ±15% (WMO 2014).

Today, the largest estimated anthropogenically-influenced MB source is biomass burning in agriculture and biofuel use, approaching 25 k tonnes in 2012, and this is not controlled under the Montreal Protocol. The uncertainty of the biomass burning MB emissions is about ±40% (WMO 2014). As discussed above there is a large unknown source of a similar amount possibly from industrial processes or natural systems. Agricultural crops (rapeseed, rice) release about 5 k tonnes of MB per year and leaded petroleum about 2 k tonnes per year. The uncertainty on both these sources is about ±50% (WMO 2014). Potential minor sources of MB emissions are from uses as a chemical feedstock. Overall total (natural and anthropogenic) MB emissions have declined from in excess of 120 k tonnes per year in 1995-1998 to 85 k tonnes in 2012, driven almost entirely by the declining consumption of non-QPS MB (Table 8-1, Figure 8-1).

In 1995-1998, manufactured MB used in fumigation (48 k tonnes/year) accounted for about 40% of all identified MB sources; by 2012, thanks to countries taking steps to reduce the use of MB for non-QPS purposes, fumigation use had declined to just over 10% (10 k tonnes) of all identified sources, with QPS use accounting for about 8% of all identified sources. The total fumigation use of MB has declined by 80% over this period and the non-QPS fumigation use has declined by over 90%. The impact of the relatively recent and currently limited MB recapture on the global MB budget is likely to be small (less than 200 tonnes recaptured globally per annum (MBTOC estimate).

FIGURE. 8-1. TOTAL AND ANTHROPOGENIC GLOBAL MB EMISSIONS



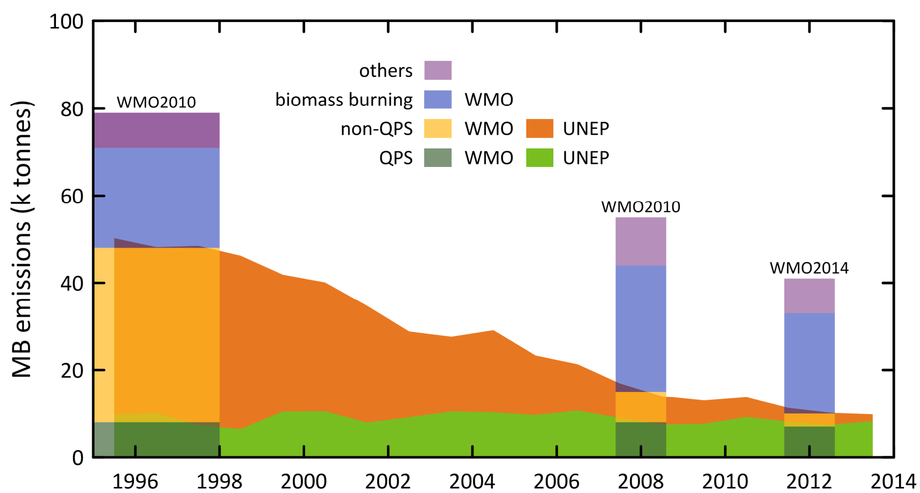


Figure 8.1. Total (top) and anthropogenic (bottom) global methyl bromide emissions from atmospheric data (AGAGE; Rigby et al., 2011, 2014; see text below), and as reported in WMO 2010 and 2014 (Montzka & Reimann, 2011; Carpenter & Reimann, 2014) and as derived from UNEP consumption data (http://ozone.unep.org/Data_ Reporting/Data_Access/ , see text below) and a fumigation emissions model (UNEP: Montzka & Reimann, 2011). Current non-fumigation sources are largely oceans (40%), biomass burning (25%) and vegetation (20%).

TABLE 8-1. ESTIMATED GLOBAL METHYL BROMIDE SOURCES (EMISSIONS) AND SINKS (K TONNES): 1996-1998, 2008, 2012 (MONTZKA & REIMANN, 2011; CARPENTER & REIMANN, 2014)

Sources	1995-1998[a,b]	2008[c]	2012[a]	Comments
Anthropogenic	80	56	41	
fumigation: non-QPS	40	7	3	only source controlled by MP
fumigation: QPS	8	8	7	
biomass burning	23	29	23	biofuels, open-field
rapeseed	5	5	5	
leaded petroleum	3	<6	<3	
rice agriculture	<1	<1	<1	
Natural	43	54	44	
oceans	32	42	32	
salt marsh	7	7	7	
plants	2	2	2	mangroves, shrubs
fungus	2	2	2	
wetlands	<1	<1	<1	largely peat lands
Total Sources	123	111	85	

Sinks	1995-1998[a]	2008[b]	2012[a]	Comments
atmosphere	-81	-67	-60	oxidation, photolysis
soils	-40	-32	-27	
oceans	-41	-49	-30	
Total Sinks	**-162**	**-148**	**-117**	

[a] Carpenter *et al.,* 2014

[b] Source uncertainty ranges (WMO 2014): fumigation (±15%), biomass burning (±40%), petroleum (±60%); other terrestrial (±50%), oceans (±30%); sink uncertainty ranges (WMO 2014): atmosphere (±15%), soil (±30%), ocean (±30% (WMO 2014)

[c] Montzka *et al.,* 2011

8.3. Summary of impact of regulation of MB emissions

By 2013, the MB phase-out has led to a 33% fall in total MB (65% of anthropogenic bromine) in the troposphere from the mid-1990s as measured at Cape Grim, Tasmania, Australia (Figure 8-1). Owing to the short atmospheric half-life of MB (0.7 years) in the stratosphere, changes in emission of MB at ground level are rapidly reflected in changes in tropospheric and stratospheric MB concentrations. This is in contrast to almost all other ODSs regulated under the Protocol as these usually have much longer atmospheric half-lives. The Scientific Assessment Panel (WMO, 2007) rated the importance of MB in contributing to ozone layer recovery as higher than previously calculated, because MB atmospheric reductions were greater than previously anticipated.

The 2010 Science Assessment of Ozone Depletion: 2010 report (Montzka *et al.* 2011) reported that by 2008 'total tropospheric bromine had decreased from its peak values in 1998', and ' total bromine in the stratosphere is no longer increasing and showing signs of decreasing slightly'**.** These recent changes have largely been a consequence of regulation and phase out of MB.

In 2010, it was reported (Porter *et al*. 2010) that prior to the onset of the widespread use of MB as a soil and structural fumigant in the 1960s, the historical background or baseline concentration of MB in the atmosphere was around 5.3 ppt (Figures 8-1 and

8-2). The concentration then grew rapidly through the 1970s to the late 1990s due to large anthropogenic (man-made) use of MB (up to 72,000 tonnes annually). In the mid 1990's the concentration reached 8-9 ppt (about 60% above the 1950s natural baseline concentrations), but started falling in the late 1990s as a result of the MB reductions imposed by the Montreal Protocol. The rate of decline has been relatively constant and by 2014, this level has fallen to nearly 6 ppt as measured in 2013 (Figs 8-2 and 8-3).

In 2003, it was predicted that MB levels in the southern hemisphere would fall to about 7 ppt before levelling off (Fig. 9.3, A1 WMO, 2003). However, by 2007 the levels had continued to fall to 6.5 ppt and show signs of falling further. As discussed above recent measurements and modelling show that the MB has fallen to nearly 6 ppt, more than anticipated by recent scenario modelling (WMO 2011, WMO 2014). It is clear is that the Montreal Protocol restrictions on the use of MB are having greater impact on atmospheric MB than thought possible 10 years previously.

The latest WMO scenarios (Fig. 8-3, A1 WMO, 2014) suggest that further reductions in atmospheric concentrations are possible over the next few years, but will only occur if the remaining non-QPS uses in developing countries (A5 Parties) and the few non-A5 and A5 critical uses are phased out, and if emissions or use of MB for QPS are reduced significantly. In 2014, the use of MB for QPS was at least three times the total used for non-QPS in non-A5 and A5 countries. The estimated MB emissions from QPS in 2009 are 8 Gg (8000 tonnes, Table 8-1).

FIG. 8-2. IMPACT OF MB RESTRICTIONS IN NON-QPS USE ON REDUCTION IN BROMINE CONCENTRATIONS IN THE TROPOSPHERE SINCE THE LATE 1990'S*

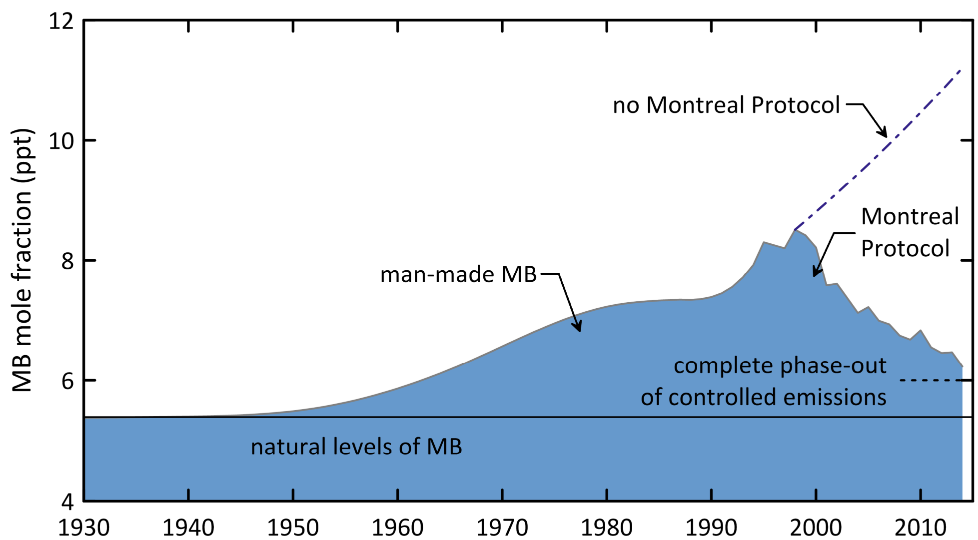
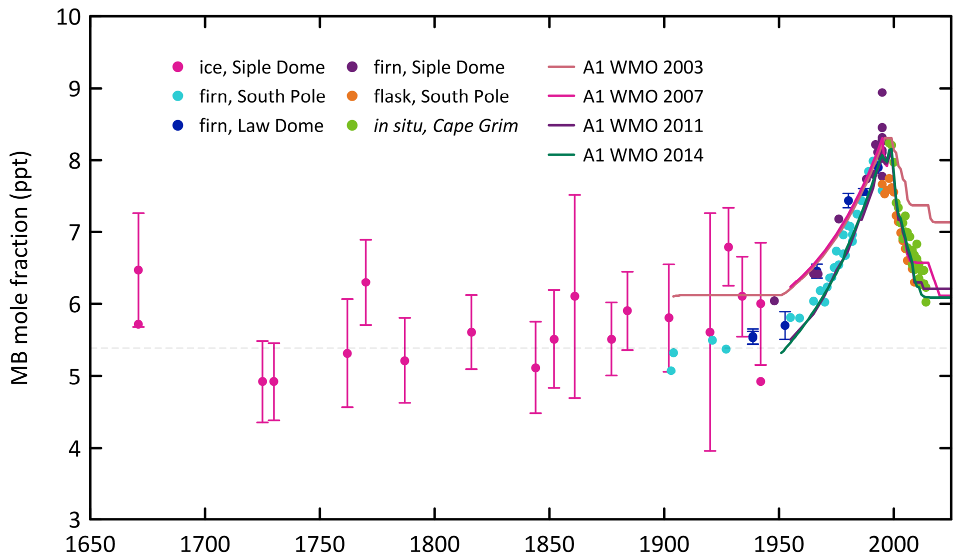


Fig. 8-2. Based on MB data from Antarctic air (firn) and Cape Grim, Tasmania. The *solid line* indicates MB levels from natural sources (i.e. the historic baseline); the *dashed line* indicates the approximate level that MB concentrations would fall to if all non-QPS MB uses were phased-out. The possible MB growth scenario without the regulations of the Montreal Protocol (1.7% per year) is estimated from atmospheric MB trends 1989-1998.

FIGURE. 8-3 HISTORIC METHYL BROMIDE MEASUREMENTS (PPT = 10 12 MOLAR) IN THE SOUTHERN HEMISPHERE OVER THE PAST 350 YEARS (THE DASHED LINE REPRESENTS THE APPROXIMATE NATURAL MB EQUILIBRIUM).



MB data are from Cape Grim, Tasmania, and various atmospheric and ice/firn sampling sites in Antarctica compared to modelled CH 3 Br levels in 2003, 2007, 2011, 2015 (WMO) updated from summary in Porter *et al*., 2010

FIG. 8-4. MAN-MADE (QPS + NON-QPS) AND TOTAL (FROM ATMOSPHERIC DATA) GLOBAL EMISSIONS OF METHYL BROMIDE

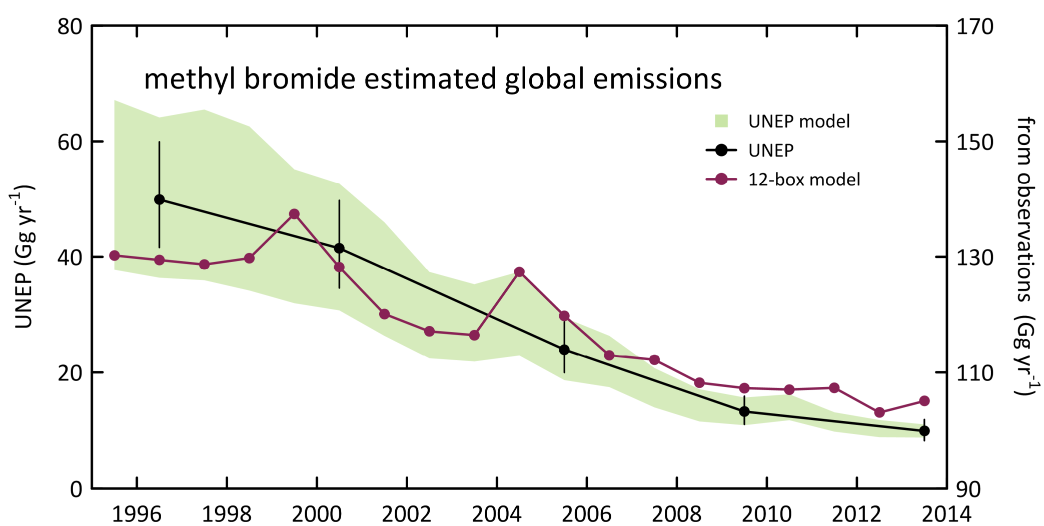


Fig. 8-4. Estimated emissions of anthropogenic (man-made) methyl bromide (MB) from fumigation (left axis), including QPS, using the UNEP model (green range); UNEP consumption data (black) for 1996, 2000, 2005, 2009 and 2013, sourced from either the MBTOC Assessment Reports of 1998, 2002, 2006 and 2010 or data reported by Parties under Article 7 to the Ozone Secretariat. The 12-box model data (red) use AGAGE global atmospheric observations (Rigby *et al*. 2014) (right axis).

8.4. MB emissions from current uses for soil, commodities and structures

All the MB applied during fumigation will be released to the atmosphere excepting that reacting irreversibly with treated materials (e.g. soil components, commodities or structural materials) or which is recaptured and destroyed. Since there is insignificant use of recapture and destruction at this time to influence significantly global emissions, the only 'sink' within the MB fumigation process is a reaction to give inorganic, non-volatile bromide ion. From the capacities of currently installed recapture equipment known to MBTOC, is estimated that the MB recaptured and destroyed in 2013 was not greater than 200 tonnes.
Table 8-2 includes estimates for emissions from application to soils. It is not possible to give a precise average emission as the distribution of emissions over the global range of practices cannot be estimated because of lack of data. However, it is likely that the true value lies within the range quoted.

TABLE 8-2. ESTIMATED GLOBAL USAGE OF MB AND EMISSIONS TO ATMOSPHERE IN 2013 FOR DIFFERENT CATEGORIES OF FUMIGATION BY MAJOR USE CATEGORY, INCLUDING QPS USE (EXCLUDES FEEDSTOCK).

Type of fumigation and commodity/use	Estimated usage		Estimated emissions	
	tonnes	%	tonnes	% (*a*)
Non QPS				
Preplant soil fumigation	2200	19	1408	64 (46-91)
Structures, commodities and perishables	290	2.5	265	92 (85-98)
Sub Total- non QPS	***2490***	***22***	***1673***	***67***
QPS				
Preplant soil fumigation	1650	15	1056	64 (46-91)
Timber and wooden packaging	4402	39	3874	88
Durables and miscellaneous	2063	18	1537	75 (51-98)
Perishables	701	6.2	641	92 (85-98)
Sub Total- QPS	***8816***	***78***	***7108***	***81***
Total estimated fumigant use	**11,306**	**100**	**7539 - 10370**	**67 - 91**
Best estimate over all categories			**8781**	77 *(c)*

a For original sources of estimates, see MBTOC 1995 with minor subsequent adjustments

b Fluxes of MB through LPBF tarps are very low, but loss can occur after lifting the tarp. This is very dependent on the duration of tarping and the soil type and conditions (Yates, 2005; Fraser *et al.*, 2006). Experimentally, very low emissions can be obtained (e.g. 6%, Yates, 2005; <4% Yates et al, 2009). Regulations in 2013 prevented use of barrier films in specific places (e.g. California) and price and availability mean they are not used in some soil sectors in many countries.

c MBTOC recognises that the true value of emissions may differ from this best estimate.

The overall usage figures given in Table 8-2 are derived from a combination of reported 2013 global production for QPS, usage in 2013 in Article 5 and non-Article 5 countries as authorised for CUE purposes (Chapter 3, Section 3.7.5) and use of stockpiles as reported annually by Parties under Decision XVI/6. The usage figures for the individual sectors are based on tonnages estimated from these data sources.

Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere are estimated by MBTOC to be 41 – 91%, 85 - 98%, 76 – 88% and 90 - 98% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 67 - 91% overall emission from agricultural and related uses, with a mean estimate of overall emissions of 77%.
Best estimates of annual MB emissions from fumigation use in 2013 of 8781 tonnes (Table 8-2) were 52% lower than in 2009, which totalled 17,041 tonnes. There have been substantial reductions in usage for soil fumigations for controlled uses, counterbalanced to some extent by increases in fumigation of timber and wood packaging materials treated to meet Quarantine and Preshipment requirements and the recategorisation of some soils uses to QPS. It appears that the usage on perishables was overestimated in the 1994 and 1998 MBTOC Assessments.
Estimated usage is based on QPS consumption data (this Assessment), authorised CUE use for 2013 and MBTOC survey of Article 5(1) consumption and use, excluding feedstock. Reported use of stocks is included in calculations but no allowance for unreported use (see Table 8.2)

8.5. Emission Reduction through Better Containment

MB is a gas at normal ambient temperatures (boiling point at normal atmospheric pressure: 4°C). During fumigation some of the gas becomes sorbed on the treated materials or the packaging/palleting in commodity treatments or into the soil for preplant treatments. Some of the sorbed MB remains unchanged and will air off at the end of the treatment, but a portion of the sorbed MB is converted into non-volatile residues. Except for this portion, all the MB applied during fumigation will eventually be emitted to the atmosphere. During any fumigation operation there are four distinct sources or opportunities for MB to be emitted to the atmosphere:

i. By leakage during the set up and actual fumigation treatment.

ii. During unintentional discharge of some unreacted MB during applications when changing cylinders, lifting rigs from soil to reverse direction, etc.

iii. During international 'off gassing' or discharge of unreacted MB after completion of fumigation of commodities and structures after a set exposure period.

iv. Following treatment when the treated soil, commodity or structure emits any sorbed, unreacted MB over an extended period of time.

All but the third situation can be controlled or reduced by better containment (sealing and film permeability) of the fumigation site (Section 8.3 (soil treatments) and fumigation enclosure (Section 8.6 (commodities)). Leakage and uncontrolled emissions in these instances are undesirable. They reduce effectiveness of the treatment as well as having worker safety and local air quality implications. Reduction of emissions in intentional discharge can be controlled by a reduction in MB dosage applied or by recapture of the MB followed by recycling, reclamation or destruction (Sections 8.8 and 8.9). For most commodity and structural fumigation operations, intentional venting following fumigation results in the largest discharge (emission) to the atmosphere. Theoretically, this MB is available for recapture and reuse or destruction, although there are several problems that lead to reduced recapture efficiencies.

Even though only a small fraction of added gas may be present after termination of a fumigation and subsequent airing it can, lead to sufficient air concentrations in some situations to present possible health hazards to workers and bystanders.

8.5.1. Soil fumigation

It is generally understood, that MB emissions to the atmosphere from soil fumigation can come from any of three major sources:

v. permeation through plastic sheets and leakage through joins and holes during fumigation;

vi. leakage from edges during fumigation and edges when laying and venting injection rigs; and

vii. desorption and venting from soil after lifting the sheets after fumigation.

Degradation is due to reaction with soil organic matter and some mineral constituents as well as other reaction pathways such as hydrolysis (De Heer *et al.* 1983; Duncan and Yates 2003).

8.5.2. Use of barrier films and other plastic covers to reduce emissions

Barrier films have become a very effective measure to reduce emissions by up to 50%. Since the 1998 assessment report there have been many studies looking at the advantages of a number of different types of barrier films. These have progressively included testing and application of virtually impermeable films (VIF films), semi-impermeable films (SIF) and totally impermeable films (TIF). VIF films typically comprise a LLDPE sandwich containing nylon; SIF films include a LDPE sandwich containing HDPE and TIF comprise a polyethylene sandwich containing two adhesive layers ("Admer") and a central layer of ethyl vinyl alcohol ("EVAL"). Studies under field conditions in a number of regions (Table 9.2), together with the large scale adoption of barrier films in Europe support the use of these films as a means to reduce MB dosage rates and emissions. Controlled studies have also shown substantial reductions in MB emissions using a number of techniques in addition to changing film type (Yates 2005; Fraser *et al.* 2006).
It is estimated in commercial practice, that emission ranges from 40-92% occur from the use of standard polyethylene (PE) and 35 - 87% for the wide range of barrier films that have been used (Table 8-2). The relatively high emission rates quoted are because figures include the emission after the tarp is removed. Recent studies with TIF Totally Impermeable Films) (Chow *et al.* 2009) have shown reductions in emissions of 22- 45% of the applied MB (Ntow *et al.* 2009).Under experimental conditions with full tarping, not strip treatment, and extended exposure periods, emissions were shown to be even lower during tarping, ie. < 6% of applied MB (Yates 2005, Papiernik *et al.* 2004; Ntow *et al.* 2009; Yates *et al*. 2009). Ntow *et al.* (2009) showed that when compared to standard PE films, TIF films can reduce peak emissions during the first 24 hours by up to 85% when MB was applied below 45cm; 80.5% when potassium thiosulphate was applied and 67% when the TIF film was used with shallow shank injection of MB at 30 cm. TIF films may be so effective that off gassing becomes a greater issue when the tarp is lifted and this may pose concerns to worker safety. Fraser *et al.* (2006) stated that a Virtually Impermeable Film (VIF), a semipermeable barrier film (metallised with aluminium) and more recently TIF were 6 to 9 times more effective in blocking MB flux to the atmosphere during fumigation and recent studies have continued to show that this can lead to a reduction

in dosage rates of at least 30-50 % for similar efficacy (Villahoz *et al*. 2008; Gao *et al*. 2013; Qin *et al*. 2011; Qin *et al*. 2014).

Table 8-3 shows that typically equivalent effectiveness is achieved with 25 –50% less MB dosage applied under the LPBF films (VIF, SIF (semi-impermeable films), TIF) compared with normal polyethylene fumigation films. Recent advances in the cost and technical performance of barrier films, especially metallised polyethylene films have reduced cost and extended their suitability for use with MB and also several of the fumigant alternatives, e.g. Pic clor 60 (60% chloropicrin/40% 1, 3-D); methyl iodide, 1,3-D (Fennimore *et al.* 2006; Gao *et al.* 2009) alternatives. Previous difficulties with sealing and gluing barrier films are no longer seen as a technical barrier to their implementation as new application technologies (i.e. glues, polyethylene edges and perforated films) have solved earlier problems.

The use of low permeability barrier films (VIF or equivalent) became compulsory in the member states of the European Union (EC Regulation 2037/2000) in 2000 and were used with the majority of critical uses granted in the US outside of California which had a regulation (California Code of Regulations Title 3 Section 6450(e)) against their use until recently. The Californian regulation was implemented because of concerns over possible worker exposure due to off gassing of MB when the film is removed or when seedlings are planted, but this has since been revised. In most other regions of the world, LPBF films are considered technically feasible, but may not be practical for MB fumigation because of small areas leading to lack of availability or high cost.

There is some use of barrier films in A5 countries, but generally the remaining uses for preplant soil use is with standard permeable PE films due to their low cost, however all remaining uses of MB should be encouraged to use such films to reduce dosage rates and emissions.

8.5.3. Adjustments of dosage rates in MB/Pic formulations to reduce emissions

Barrier films reduce MB emissions from soil fumigation by retaining the introduced MB in the soil for extended periods to allow the gas to degrade by reaction with soil components. Maximal degradation and thus reduction in emissions is obtained (Yates *et al.* 1998) when:

- the entire field is covered with barrier film;
- all film strip over-laps are well glued and sealed;
- the barrier film edges are sealed (buried under soil);
- the MB is injected deeply in the soil;
- the film is kept on the field, completely sealed, for more than 10 days; and
- the soil temperature, moisture and organic matter content are optimal - medium temperatures, moist soil, and high organic matter.

Barrier films are less effective at reducing MB emissions from soil fumigation (Rice *et al.* 1996; Thomas 1998; Wang *et al.* 1999, Yates *et al.* 2009) when:

- only part of the field is covered with barrier film (i. e. with strip or bed fumigation);
- any of the film strip over-laps become unglued or are otherwise unsealed;
- any of the film edges anywhere around the field become unsealed;
- the film seal is broken before 10 days have passed; and

- soil temperature, moisture, organic matter are in any way sub-optimal (hot, dry soil or very wet soil with little organic matter).

Studies have shown that with traditionally laid LDPE or HDPE films, most unreacted MB either passed through the films or was emitted from the edges of the film (Yates, 2005). In general, fumigation films remain in place for 5 to 7 days and with standard films this ensures maximum effectiveness of the applied dosage. With barrier films, even though lower dosages of MB are used, longer periods of tarping may be required to ensure complete degradation of the applied MB, to effectively reduce MB emissions and to avoid off gassing of unreacted MB when the tarps are removed.

8.5.4. Adjustments of dosage rates in MB/Pic formulations to reduce emissions

One key strategy to reduce MB dosage and therefore relative emissions has been the adoption of MB:Pic formulations with lower concentrations of MB (e.g. MB:Pic 50:50, 30:70 or less). These formulations are considered to be equally as effective in controlling soilborne pathogens as formulations containing higher quantities of MB (e.g. 98:2, 67:33) (e. g. Porter *et al.,* 1997; Melgarejo *et al.,* 2001; Lopez-Aranda *et al.,* 2003). Formulations containing high proportions of chloropicrin in mixtures with MB have been adopted widely by many countries to meet Montreal Protocol restrictions where such formulations are registered or otherwise permitted. Their use can be achieved with similar application machinery which allows co-injection of MB and chloropicrin or by use of premixed formulations. Consistent performance has been demonstrated with both barrier (Table 9.2.) and non barrier films. Fig 9.2 demonstrates the reduction in dosage rates achievable with barrier films compared to standard fumigation films

8.5.5. Other cultural management methods to reduce emissions

Irrespective of what surface barrier is used to contain MB during soil fumigation, there are a number of key factors, which affect emissions of MB during soil fumigation. Past reports (Yates, 2005, 2006, Yates *et al.* 2009) have shown that manipulation of many other factors can reduce emissions of applied MB, but the extent to which these factors are practiced by industry is unreported. These studies concluded that emissions can be reduced by improving containment of the MB gas and by increasing degradation time, however natural soil degradation is insufficient to reduce fumigant emissions to the atmosphere. Methods to improve containment included barrier films as discussed above, but also improvements in cultural factors of the cropping system including soil management, e.g. strip verses broadacre treatment, increased containment time, addition of sulphur containing fertilisers, increasing organic matter, soil water content, soil compaction and surface sealing with water.
Previous assessment reports have covered these factors, however as they are important they are repeated here for reference, especially as the A5 Parties are now applying for critical uses for which the information contained here could assist reduction of emissions of MB.

8.5.5.1. Soil characteristics

Studies of MB degradation in various soil types have shown that soil type greatly affects degradation, depending upon the time the MB is held in the soil. High organic matter and soil water content and increasing bulk densities are major factors, which assist reduction in emissions (Gan *et al.,* 1997; Thomas, 1998; Yates, 2005).

8.5.5.2. Fumigation period

Tarps left on soil for longer periods increase the residence time of the MB in the soil, thereby decreasing emissions. Wang *et al.* (1997a) demonstrated that emissions were reduced from 64% with PE tarps to 37.5% with VIF over a 5 day exposure, and from 56.4% to less than 3% respectively for a 10 day exposure with a sandy loam soil.

8.5.5.3. Irrigation, organic amendments and fertilisers

MB emissions can be reduced if the air filled porosity of the soil is reduced by increasing the water content. The presence of water increases the hydrolysis of MB to bromine ions. Irrigation reduces the variability in the distribution of MB in the soil, thus achieving a more reliable fumigation result (Wang *et al.,* 1997a).

In laboratory and field studies, Yates (2005, 2006) reported that the use of ammonium thiosulphate fertilizer added to the surface of soil could reduce emissions from 60 to less than 10%, and irrigation and surface sealing with water were an inexpensive way to reduce emissions.

The above results supported earlier work that addition of nitrogen fertilisers and organic amendments enhance degradation of MB. Lime, ammonia fertiliser and ammonia oxidation bacteria also increased the degradation rate of MB in soil (Ou *et al.,* 1997; Gan *et al*., 1997). These products have been shown to enhance degradation of MB. However, further research is required to identify their use for emission reduction.

8.5.5.4. Soil surface structure

A light rolling (pressing) of soil immediately after shank application closes furrows and seals the soil surface. This decreases direct emission from the injection points (channelling) within the first 24 hours after application and may assist reduction of total emissions (Anon 1997). Yates (2005) showed that surface compaction could reduce emissions from 90 to 64% of the applied MB.

8.5.5.5. Depth of injection

Emissions of MB can be reduced by injecting the material deep into the soil. The extent of the reduction depends upon soil conditions. For example, in field and laboratory studies, increasing the depth of injection from roughly 25 to 60 cm resulted in a 40% decrease in emissions under tarped conditions (Yates *et al.,* 1996). In laboratory studies, it was shown that increasing injection depth delays the occurrence of maximum volatilisation flux and also decreases cumulative emissions (Gan *et al.,* 1997; Yates, 2005). Deeper shank injections increased the path distance, thus increasing the residence time for degradation (Wang *et al.,* 1997ab) and minimising emissions.

8.5.5.6. Broadacre vs. strip

Strip fumigation (bed fumigation) can reduce the amount of MB applied by 20-40% as only the crop rows are treated rather than the entire field. This technique was common in many vegetable crops and most strawberry crops outside California before phase out. However, the ‘edge effect’ predominates and losses of MB from the edge of the bed tends to offset some of the advantages of strip fumigation with regard to emission reduction.

8.5.6. Regulatory practices to reduce MB emissions from soil

There are a number of practices in use in various parts of the world that result in reduced MB emissions from soil treatments, including:

- Limiting the frequency of MB fumigation by requiring intervals of 12–60 months between treatments. Alternative treatment methods could be implemented in the intervening period such as IPM, steam, solarisation, alternative fumigants and predatory fungi treatments. Reductions of 17–50% are feasible by implementing a reduction in fumigation frequency (refer to Table 8.1 in Anon. 1997).
- Imposing permit systems which could ensure that only technically necessary fumigation would be carried out (e.g. The Netherlands in 1981, Belgium 2005).
- Adjusting pesticide controls. For instance, MBTOC has suggested maximum dosage rates for specific uses, which suggest the likely maximum dosage rate required to achieve effectiveness (TEAP 2010).
- Regulating the users of MB to contractors only and licencing and training operators responsible for fumigation.
- Where possible, shifting practices from ‘hot gas’ methods using high concentrations of MB to soil injection that uses mixtures of MB/chloropicrin at lower MB concentrations, or substitute other chemical and non chemical treatments.

Table 8-3. Relative effectiveness of MB/Pic formulations applied in combination with low permeability barrier films (LPBF)[A] compared to the commercial standard MB/Pic formulation applied under standard low density polyethylene films (LDPF). [A] The LBPF films include virtually impermeable (VIF), semi-impermeable (SIF) and totally impermeable films (TIF)

Country	Region	Commodity	Brand or Type of Barrier Film	Untreated	Methyl Bromide/Chloropicrin Mixtures (Product rate per treated area)														Notes	Reference
					Std film		Barrier Film – Relative yield compared to standard polyethylene													
				Yield	MB/Pic Formuln.	Product Rate	Not Spec	98:2	98:2	67:33	67:33	67:33	67:33	67:33	67:33	50:50	33:67			
						kg/ha	300	400	300	98	196	200	294	336	392	200	200			
MB Dosage rate (g/m2)								392	294	66	131	134	197	225	263	100	66			
Spain	Vinderos	Strawb. Runner	VIF - NotSpec	74	50:50	400											93	Fusarium, Phytophthora, Pythium, Rhizoctonia and Verticillium	De Cal et al 2004 a,b
	Navalmanzano			78	50:50	400											80		
Spain	Vinderos	Strawb. Runner	VIF - Not Spec	68	50:50	400										114	102	Fusarium, Cladosporium, Rhizoctonia	Melgarejo et al 2003
	Navalmanzano			34	50:50	400										76	75		
Spain	Avitorejo	Strawb. Fruit	VIF - Not Spec		50:50	400											97	2003 results	Lopez-Aranda et al 2003
	Malvinas				50:50	400											99		
Spain	Valencia	Strawb. Fruit	VIF - Not Spec	59	Not Spec	600	94											1998 Fusarium At 10cm & 30cm	Bartual et al 2002
				53	Not Spec	600	93											1999 results	
Spain	Avitorejo	Strawb. Fruit	VIF - Not Spec	80	67:33	400										112		Meloidogyne and weeds (unspec.)	Lopez-Aranda et al 2001a
	Tariquejo			54	67:33	400										106			
Spain	Moguer/Cartaya	Strawb. Runner	VIF - Not Spec		50:50	392										99		Inoculum not specified	Lopez-Aranda et al 2001b
Spain	Cabeza, Nav.	Strawb. Runner	VIF - Not Spec	74	67:33	400						105, 92						1998 Two sites	Melgarejo et al 2001
	Arevalo, Nav.			84	50:50	400										104, 104		1999 results, nurseries	
	Vinaderos, Nav.			49	50:50	400										95, 123		2000 results, nurseries	
Spain	Huelva	Strawb. Fruit	VIF - Not Spec	82	67:33	400						101						1997-1998 Inoc.unspecified	Lopez-Aranda et al 2000
				72	67:33	400						102						1998-1999 Inoc. Unspecified	
				68	67:33	400						109						1999-2000 Inoc. Unspecified	

Country	Region	Commodity	Brand or Type of Barrier Film	Untreated	Methyl Bromide/Chloropicrin Mixtures (Product rate per treated area)													Notes	Reference
				Std film			Barrier Film – Relative yield compared to standard polyethylene												
				Yield	MB/Pic Formuln.	Product Rate	Not Spec	98:2	98:2	67:33	67:33	67:33	67:33	67:33	67:33	50:50	33:67		
						kg/ha	300	400	300	98	196	200	294	336	392	200	200		
MB Dosage rate (g/m2)								**392**	**294**	**66**	**131**	**134**	**197**	**225**	**263**	**100**	**66**		
Spain	Moncada	Strawb. Fruit	VIF - Not Spec	60	98:2	600			95									1998 No major pathogens but Fusarium buried 10cm&30cm.	Cebolla et al 1999
				54	98:2	600			91										
France	Douville	Strawb. Fruit	VIF - Not Spec	65	Not Spec	800		99										Inoculum not specified	Fritsch 1998
NZ	Havelock North	Strawb. Fruit	VIF - Not Spec	83	67:33	500								98				Phytophthora present	Horner 1999
USA	Florida	Pepper	VIF Plastopil	69	67:33	392					78							Nutgrass	Gilreath et al.s 2005
			VIF Plastopil	69	67:33	392				99								Present	
			VIF Vikase	69	67:33	392					83								
			VIF Vikase	69	67:33	392				86									
USA	Florida	Strawb Fruit, Cantaloupe	Barrier - Pliant, Metallised		98:2 67:33	Trials on 18 Commercial Farms between 2000-2004; no increase in disease or weeds when rates reduced up to 50% under VIF wrt. polyethylene												Nutgrass and pathogens present	Noling and Gilreath 2004
USA	California	Strawb. Fruit	VIF - Not Spec	72	67:33	336								108				Inoculum not specified	Ajwa et al 2004
				80	67:33	392									96				
USA	Florida	Tomato	VIF - Not Spec	31	67:33	392					111		93		114			Nutgrass and rootknot nematodes	Hamill et al 2004
USA	California	Strawb. Fruit	VIF - Not Spec	75	67:33	392									106				Ajwa et al 2003, 2004, 2009
				83	67:33	392									111			Watsonville, high pathogen pressure	
				65	67:33	392									102				
USA	Florida	Tomato	VIF - Not Spec		67:33	392	"No significant reduction in yield"												Noling et al 2001
USA	California	Strawb. Fruit	VIF - Not Spec	45	67:33	364									116				Duniway et al 1998
USA	Georgia	Nurseries	VIF – not spec		67:33	389	See reference												Carey and Godbehere, 2004
USA	California	Roses			67:33 98ˇ2	392 392	See reference												Hanson et al, 2006; 2009
USA	Florida	Pepper	VIF – not spec		67:33	392	See reference												Santos and Gilreath, 2004
USA	Florida	Pepper	VIF – not spec		67:33	392	See reference												Santos et al, 2005
USA	California	Ornamentals	VIF – not spec		67:33	392	See reference												Klose 2007, 2008
Unweighted averages (relative % yield)				66			94	99	93	93		102		103	108	104	91		

8.6. *Structural and commodity fumigation - sealing for emission minimisation*

Post-harvest disinfestations of commodities and structures using MB are performed, or should be performed, under well sealed conditions that limit loss of the fumigant to atmosphere during the exposure period. Commodity fumigations may be carried out either in fixed-wall structures such as fumigation chambers, in transport vehicles including containers and ships or under gastight tarpaulins.

Controlled conditions allow manipulation of the key fumigation parameters: dosage, temperature and time. Greater control of emissions is potentially more easily achieved in an enclosed structure than in relatively uncontrolled field situations. Providing the fumigation enclosure is relatively gastight, the dosage of MB can be reduced by increasing either the temperature or the exposure time, or both, providing the commodity is able to tolerate the conditions. Forced air circulation reduces the range of concentration - time (*ct*) products experienced within the enclosure, thus reducing the need for high dosage rates to compensate for areas that may otherwise receive insufficient concentrations of fumigant.

As noted in previous Assessments, developing high temperature schedules, with or without longer fumigation durations, could also reduce MB use providing the marketability, including food safety of the produce is acceptable. Improving the gas tightness of fumigation facilities will minimise leakage of MB into the atmosphere. Simple test criteria have long been available to the industry for determining the gas tightness of chambers (e.g.Bond, 1984) and these may be part of the mandatory fumigation requirements for trade (Quarantine treatments) of many perishable commodities e.g. as in APHIS PPQ manual (http://www.aphis.usda.gov/import_export/plants/manuals/index.shtml) .

8.7. *Fumigant Recapture and Destruction*

8.7.1. Scope for emission reduction by recapture

Parties have been urged to minimise emissions of MB in situations where they still use MB and are unable to adopt non-ozone depleting alternatives. This includes both QPS treatments and fumigations carried out under CUEs (Decisions VII/7(c), IX/6). One approach to minimising emissions is to adopt recapture technology, with subsequent destruction or reuse of the MB.

The discussion below concentrates mainly on availability and operation of recapture technologies for well-contained commodity and structural fumigations, including QPS applications. Some attempts have been made to apply recapture to soil fumigations, but the geometry and situation of soil fumigations render this problematic, and no systems, to knowledge of MBTOC, are in current use.

At this time, there remain no processes for MB approved as a destruction process under Decision XV/9 and listed in any updates to annex II of the report of 15 MOP that listed approved destruction processes by source and destruction method. However, the situation is currently under review (Decision XXII/10). Parties have previously submitted information on recapture processes for MB in use, following Decision XVII/11. This information and a review thereof is given in TEAP Report (TEAP 2006).

8.7.2. Efficiencies and potential quantities of MB available for recapture

For maximum 'recapturable' MB from a fumigation, losses within and from the system must be minimised. During any fumigation operation there four distinct opportunities for MB to be lost or emitted to the atmosphere:

i. by leakage during the actual fumigation treatment.
ii. during venting of the fumigation space immediately after fumigation or removal of the cover sheets where a deliberate discharge to the atmosphere takes place.
iii. following treatment when the treated commodity, packaging or structure slowly emits any sorbed MB.
iv. by reaction when sorbed MB is converted irreversibly to nonvolatile products

Situation (i) and, to some extent, (iii) can be controlled or reduced by better containment of the fumigation site. Leakage in these instances is undesirable from the fumigation perspective as it reduces the effectiveness of the treatment, as well as having worker safety implications (e.g. Baur *et al.* 2009).

The proportion of added non-volatile bromide residue formed as a result of a treatment is a direct measure of the proportion of the applied MB *not* emitted to atmosphere, provided an allowance is made for natural or added bromide ion already present prior to treatment. Only the remaining MB is available for recapture and/or destruction.

The proportion of applied MB converted to fixed residues, and thus not released to the atmosphere, varies widely with the particular treatment situation and treated material. It is influenced, *inter alia*, by the mass of material within the enclosure (the filling ratio) and its temperature and moisture content, and the exposure time. Longer exposure periods, higher temperatures, higher moisture contents and greater mass of material all lead to lower potential recapturable MB.

Methyl bromide may be temporarily and reversibly lost from the gas space within the fumigation enclosure through physical sorption on or in materials in the enclosure. This includes dissolving in fats and oils, surface adsorption and capillary condensation. In a fumigation it typically takes a few hours to approach equilibrium for this reversible sorption. Subsequent to the intentional exposure to the fumigant, the sorbed MB may volatilise from the treated commodity quite slowly, sometimes taking several days to reach low levels of emission. The rate of sorption and desorption is strongly dependent on the materials treated, their state and their dimensions.

There remains remarkably little firm quantitative field data published on the production of bromide ion or other measures of loss of MB from particular systems that could be used to estimate the maximum total quantity of MB available from fumigations.

The general overall potential for recovery from enclosed space fumigation, such as almost all QPS treatments, can be estimated from the total emissions expected. Estimated emissions and ranges for various categories of fumigation, including commodity and structural fumigation, are given in Table 8-2 (above).

As an approximation, most postharvest and structural fumigations have at least 85% of the applied dosage present at the end of the fumigation as MB in some form, *including* that lost by leakage. Fumigations of oily and high protein materials, such as nuts or oilseeds, may have 50% or even less available. The proportion of this theoretical limit that can actually be recaptured depends mainly on how much is lost by from the enclosure during the fumigation.

TEAP (2002) estimated that about 86% of the applied MB used in commodity and structural (space) fumigations remained as unreacted MB in some form at the end of the fumigation exposure period. This figure of 86% implies an average loss by reaction of 14% of applied dosage. In practice some leakage is inevitable and the time required for total desorption may be excessive. On the basis that 15% (8% loss from leakage, 6% residual material and other inefficiencies) of the originally applied material is lost from the system under best practice, TEAP (2002) estimated that 70% of applied material could be recovered from structure, commodity and QPS fumigations. The actual figure achievable in practice will vary substantially from this average figure according to the particular situation.

Since the material that reacts irreversibly with the commodity or structures does not contribute to emissions, and the reversibly sorbed material will eventually be released and is thus potentially recapturable, the only losses from the system relate to leakage and ventilation losses. With these less than 10% per day from well sealed systems (see below), there is theoretical potential for reduction of MB emissions of more than 90% of the quantity applied through adoption of recapture and efficient containment. Almost all QPS treatments are carried out under conditions that could potentially lead to a reduction in over 90% of applied dosage being emitted to atmosphere, though this would need adoption of substantially improved containment compared with much current practice.

QPS purposes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment (TEAP 2002). For the 7,456 tonnes used for commodity and structural treatments (from Table 8-2), principally for QPS use, at 70% recapturable, 5,219tonnes could have been prevented from entering the atmosphere by the fitting of recapture and destruction equipment.

In current practice, many fumigations are conducted in a way where there are losses from the system that prevent this theoretical 70% recaptureable value being attained routinely.

Worldwide many fumigations continue to be conducted in poorly sealed enclosures, leading to high rates of leakage and gas loss. It is not uncommon to find <10% of applied MB present after a 24 h exposure, particularly with structural fumigations. For maximum potential for recapture, many fumigation enclosures would need substantially improved sealing to restrict leakage to a low level. Banks and Annis (1984) estimated loss rates of as low as 5 to 10% per day were achievable in most structures with appropriate sealing.

In good fumigation practice, such as specified by AQIS (2006), there is a residual gas level present after a fumigation. Table 8-4 gives the residual gas levels expected at various times.

TABLE 8-4. MINIMUM CONCENTRATIONS OF MB REMAINING AT VARIOUS TIMES FOR QUARANTINE FUMIGATIONS (AQIS 2006).

Time after dosing (h)	Minimum % concentration remaining
0.5	75
1	70
2	60
4	50
12	35
24	30

These values are aimed at achieving effective kill under practical quarantine conditions. They are not specifically targeted at achieving minimum emissions (losses by leakage) during fumigation. They provide a guide to what is typically achieved in good current commercial practice. With better sealing levels, relative MB concentrations remaining, even at long exposures, can be substantially improved. The figures underlie the need to minimise exposure periods if it is desirable to achieve maximum potential for recapture.

These minima represent minimum recapturable MB. They do not take into account desorbable MB. This may be as much as 50% of applied dosage with sorptive materials. Treatments of perishables are typically for less than 4 hours, but timber and durables may be exposed for 24 h or longer, to allow for full distribution and penetration of the fumigant.

The current version (IPPC 2013) of the ISPM 15 standard for treatment of solid wooden packaging materials in export trade have set a retention of 50 % of the initial standard dosage at the end of the 24h fumigation period (Table 8-5). This high level of retention is difficult to achieve in practice, requiring very good fumigation practice, including very good sealing levels and low filling ratios.

Consequently, some fumigators are adding extra MB at the start of the ISPM15 fumigations to compensate for high leakage so that specified minimum concentrations at the end of the exposure are met. This process uses additional MB and reduces the proportion of MB added that is in practice available for recapture. The level of retention of 50% of initial dosage may not be possible practically for some log fumigations carried out under gasproof sheets.

TABLE 8-5. ISPM 15 STANDARD FOR TREATMENT OF SOLID WOOD PACKAGING MATERIAL. DOSAGE RATES AND FINAL CONCENTRATIONS. (IPPC 2013).

Temperature	Dosage (g m^{-3})	Minimum concentration (g m^{-3}) at 24h:	% retention at 24 h
21°C or above	48	24	50
16°C or above	56	28	50
10°C or above	64	32	50

8.8. Efficiency of recapture

The efficiency of recapture/destruction can be described in several ways. For dilute MB sources, the same general concepts may be applied as for dilute CFC sources. These are the overall Destruction Efficiency (DE), the Recovery and Destruction Efficiency (RDE) and the Destruction and Removal Efficiency (DRE). These various measures of efficiency of destruction, and thus ozone protection, are defined (TEAP 2002, a, b; 2006).

Parties have submitted DRE information for some recapture systems in use in 2006, summarised in TEAP (2006). Equivalent information for currently installed commercial units have not been published.

Well designed, sized and operated recapture systems based on activated carbon as recapture medium have almost complete recovery of MB. Fumigant concentrations are typically 10-100 g m^{-3} entering the recapture system and much less than the low, tolerable workspace concentrations (about 0.004 g m^{-3}) on exit, giving DREs of >99.9%.

In order for a carbon-based recapturing unit to be considered for use by USDA APHIS, it must meet the following specifications (USA 2009):

A system should:

- accommodate a variety of enclosure types (portable chamber and fixed chamber)
- accommodate MB monitoring sensors in the air flow (number and placement of sensors will depend on the size of the equipment)
- accommodate the fumigant concentrations and temperature conditions listed in this (Treatment) manual
- ensure that all untreated ventilation air is under negative pressure (in the event of a leak, ambient air will leak into the system instead of contaminated air escaping from the system)
- leak-tight (includes valves, ducts, canisters)
- provide a minimum adsorptive capacity of 1 pound of MB per 10 pounds of carbon (The quality of the carbon will determine the adsorptive capacity. A lower quality carbon could cause a ration of 1 pound of MB per 20-25 pounds of carbon.)
- provide between 4 and 15 complete gas exchanges per hour
- provide flow and pressure system monitoring
- provide onsite installation, training, and continual technical support
- reduce emissions of MB by at least 80%
- retain approved fumigation and aeration times as mandated by the PPQ Treatment Manual
- not exceed 500 ppm (2 oz/1000 ft3) MB gas released to the atmosphere and provide the ability to document MB concentration levels

8.9. Commercial and developmental processes for MB recapture, with destruction or recovery

A number of techniques have been proposed or investigated for their potential to recapture MB after fumigation operations. In some cases the recaptured MB is recovered in liquid or gaseous form, but usually the MB is subsequently destroyed or released by further processing after recapture. While versions of many of the approaches given below have been in some commercial application, recapture on activated carbon is currently the main system in full scale, commercial use.

Research, developmental and industrial recapture and emission reduction systems for gas streams of methyl bromide fumigant diluted in air, as present at the end of a fumigation include:

- Capture on activated carbon, with subsequent treatment to destroy sorbed methyl bromide by rinsing with aqueous thiosulphate solution or other reagents, disposal in secure landfill and thermal (hot air or steam) desorption for reuse or further processing.

- Capture on specialised zeolite with subsequent thermal desorption and reclamation

- Liquid (aqueous) scrubbing with various nucleophilic reagents, including thiosulphate, ammonia-based mixtures and ethylene diamine

- Low temperature recondensation

- Combustion systems

- Gas phase reaction with ozone, sometimes assisted by sorption of the methyl bromide on to carbon.

- Microbial degradation

Details and discussion of these processes are given in the 2010 MBTOC Assessment Report. There is continuing research to improve operation of these recapture technologies (e.g. Vasireddy, 2014, Mitch, 2014, Hall, 2014).

Current operational commercial installations include sorption on activated carbon (Nordiko 2015, Joyce, 2014) and liquid scrubbing by unspecified nucleophilic reagent (Sword, 2014).

Economics will tend to favour destruction over recycling in situations while new MB continue to be easily obtained for QPS purposes and destruction technologies are relatively cheap, including allowance for disposal of products of the destruction system.

Despite Decisions VII/5(c) and XI/13(7) that urge Parties to adopt MB recovery and to minimise emissions for QPS MB treatments, there are no installations known to MBTOC that have been commissioned prior to 2014 specifically for ozone-layer protection. However there are increasing numbers of installations, based on active carbon systems that are designed to recapture MB after well-contained commodity treatments.

These units are being attached to MB fumigations in port areas and other urban environments to scrub emissions from fumigations to comply with local regulations for toxic gas emissions, air and environmental quality and worker safety.

Most of the recovery technologies mentioned above are complex in nature. In many cases, they are likely to be a significant part of the total cost of a new fumigation facility or to contribute significant capital cost or hire costs to apparatus associated with mobile treatment units. Most have significant running costs compared with costs of treatments

Because of the extra costs associated with recapture, it is unlikely there will be substantial adoption without some incentives or regulatory intervention. Adoption in the absence of such measures or other requirements, such as local air quality specifications, will place early adopters at a competitive disadvantage compared with those that chose not to adopt recapture.

The technologies are unlikely to become widely used to assist ozone layer protection without further international and national economic and regulatory drivers.

Recapture and recycling processes have the potential to provide a means of reducing emissions from a range of fumigation operations, and making MB supplies available as a transitional measure for uses where MB alternatives are most difficult to implement.

8.10. References

Ajwa H.A., Fennimore, S., Kabin, Z., Martin, F., Duniway, J., Browne, G., Trout, T., Kahn, A. and Daugovish, O. (2004). Strawberry yield with chloropicrin and inline in combination with metham sodium and VIF. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions 3-6 November 2004, Orlando, Florida, USA.

Ajwa, H.A.,. Fennimore, S, Kabin, Z., Martin, F., Duniway, J., Browne, G., Trout, Goodhue T R., and L. Guerrero (2003). Strawberry yield under reduced application rates of chloropicrin and InLine in combination with metham sodium and VIF. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, 3-6 November 2003, San Diego, California, USA.

Ajwa H, Sullivan D., Stanghellini M., Ntow W., Holdsworth M., and Hunzie J. (2009). Volatilization Losses of Methyl Bromide and Chloropicrin from Drip Fumigated Beds Covered with Totally Impermeable Tarp. In 'Annual International Research Conference on MB Alternatives and Emissions Reductions'Nov 10-13,San Diego, 2009.

Anon. (1997). Provision of services with regards to the technical aspects of the implementation of EC legislation on ozone depleting substances. Methyl Bromide Background May 1997. B7-8110/95/000178/MAR/D4. Technical report prepared for DGXI of the Commission of the European Communities. Prospect C&S Consultants, Brussels.

Anon (2010). The 2010 Assessment of the Scientific Assessment Panel. United Nations Environment Programme (UNEP), Nairobi, Kenya, 2010. http://ozone.unep.org/Assessment_Panels/SAP/Scientific_Assessment_2010/index.shtml

Bartual, R., Cebolla, V., Bustos, J., Giner, A., Lopez-Aranda, J. M. (2002). The Spanish project on alternatives to methyl bromide. (2): The case of strawberry in the area of Valencia. Acta Hort. 567: 431-434.

Baur, X,, Poschadel B. and Budnik L. T. (2009). High frequency of fumigants and other toxic gases in imported freight containers - underestimated occupational and community health risk. Occup Environ Med. October 26, 2009, 17 pp.

Bond, E. J. (1984). *Manual of fumigation for insect control.* FAO Plant Production and Protection Paper No. 54, FAO, Rome, 432 p.

Carpenter, L. J., S. Reimann, J. B. Burkholder, C. Clerbaux, B. D. Hall, R. Hossaini, J. C. Laube, and S. A. Yvon-Lewis. (2014) Update on Ozone-Depleting Substances (ODSs) and Other Gases of Interest to the Montreal Protocol.*Scientific Assessment of Ozone Depletion: 2014* .

Cebolla, V., Bartual, R., Giner, A and. Bustos, J. (1999). Two years effect on some alternatives to Methyl Bromide on strawberry crops. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction 1999. 1-4 November, 1999, San Diego, California, USA.

Chow, E. (2009). An update on the development of TIF mulching films In 'Annual International Research Conference on MB Alternatives and Emissions Reductions' Nov 10-13,San Diego, 2009.

Clerbaux, C. and D. Cunnold, Long-Lived Compounds, Chapter 1 in Scientific Assessment of Ozone Depletion 2006, Global Ozone Research and Monitoring Project-Report No. 50, 1.1- 1.63, WMO, Geneva, Switzerland, 2007.

Daniel, J. and G. Velders, Ozone Depletion Potentials and Global Warming Potentials, Chapter 8 in Scientific Assessment of Ozone Depletion 2006, Global Ozone Research and Monitoring Project-Report No. 50, 8.1- 1.39, WMO, Geneva, Switzerland, 2007.

De Cal, A., Martínez-Terceno, A., López-Aranda, J.M. and Melgarejo P. (2004a) Alternatives to methyl bromide in Spanish strawberry nurseries. Plant Disease 88(2): 210-214.

De Cal, A., Melgarejo, P., Martinez-Treceno, A., Salto, T., Martinez-Beringola, M. L., Garcia-Baudin, J. M., Garcia-Sinovas, D., Garcia-Mendez, E., Becerril, M., Medina, J. J., Lopez-Aranda, J. M. (2004b) Chemical alternatives to MB for strawberry nurseries in Spain. 2003 Results. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction 2004. 31 October - 3 November, 2004, Orlando, Florida, USA, pp. 17-1.

De Heer, H., Hamaker, P. and Tuinstra, C.G.M. (1983). Use of gas tight plastic films during fumigation of glasshouse soils with MB. *Acta Horticulturae*, 152, 109-126.

Dungan R. S. and Yates, S. R. (2003) Degradation of fumigant pesticides. Vadose Zone Journal 2:279-286 (2003)

Fennimore S.A., Shem-Tov S., Ajwa H., and Weber J.B.(2006) Retention of broadcast-applied fumigants with impermeable film in strawberry. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction 2006. 6-9 November 2006, Orlando, Florida. pp. 12-1 – 12-4.

Fraser, P, Coram, S., Dunse, B. Macfarling-Meure and Derek, N. (2006). Methyl bromide emissions through barrier films. CSIRO Report to Department of Primary Industries Victoria, August, 2006

Fritsch, J. (1998). Strawberries crops in France: different methods to apply methyl bromide and metam sodium in open fields. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction 1998. 7-9 December, 1998, Orlando, Florida

Gao, S., Qin, R.,Hanson, B., Wang, D., Browne, G., and Gerik, J. (2009). Measuerment and Assessment of Field Emission reductions. In 'Annual International Research Conference on MB Alternatives and Emissions Reductions' Nov 10-13,San Diego, 2009.

Gao, S., Hanson, B., Qin, R., Cabrera, J., Gerik, J., Wang, D., Browne, G. (2013). Totally impermeable film (TIF) reduces emissions in perennial crop fumigation. *California Agriculture* 67(4):217-221.

Gan, J.; Yates, S.R.; Spencer, M.V.; Yates, M.V.; Jury, W.A. (1997). Laboratory-scale measurements and simulations of effect of application methods on soil MB emission. *Journal of Environmental Quality*, 26(1) 310-317.

Gilreath J.P., Motis T.N. and Santos B.M. (2005a). *Cyperus* spp. control with reduced methyl bromide plus chloropicrin doses under virtually impermeable films. Crop Protection 24, 285-287.

Hall, W. (2014). The recapture and reuse of methyl bromide on activated carbon . Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 4-6, 2014, Orlando, Florida, USA. Paper 36.

Hamill, J. E., Dickson, D. W., T-Ou, L., Allen, L. H., Burelle, N. K. and Mendes, M. L. (2004). Reduced rates of MBR and C35 under LDPE and VIF for control of soil pests and pathogens. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions 2004. 31 October - 3 November, 2003, Orlando, Florida, USA, pp. 2-1.

Hanson, B.D., J.S. Gerik, S.M. Schneider.(2009). Evaluation of reduced Methyl Bromide rates in field grown perennial crop nurseries. Proceedings Western Society of Weed Science. 62:17.

Hanson, B., J. Gerik and S. Schneider (2006). Evaluation of reduced Methyl Bromide rates and alternative fumigants in field grown perennial crop nurseries. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, Florida, USA.

Horner, I.J. (1999). Alternative soil fumigant trials in New Zealand strawberry production. In: Annual International Research Conference on Methyl Bromide Alternatives and Emission Reductions, San Diego, California, USA

IPPC 2013. ISPM No. 15. Regulation of wood packaging material in international trade.. IPPC: Rome. 20 pp. https://www.ippc.int/sites/default/files/documents/20140630/ispm_15_2009_en_2014-06-16_201406301411--243.8%20KB.pdf

Joyce, P (2014). Commercial scale Q/PS methyl bromide emissions control. . Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 4-6, 2014, Orlando, Florida, USA. Paper 37

Klose S., H.A. Ajwa, S.S. Tov, S.A. Fennimore, K.V. Subbarao, J. D. MacDonald, H. Ferris, F. Martin, J. Gerik , M.A. Mellano and I. Greene (2007). Shank and drip applied soil fumigants as potential alternative to methyl bromide in California-grown cut flowers. In: Annual International Conference on Methyl Bromide Alternatives and Emission Reductions. Sandiago, CA, USA p. 47-1-2.

Klose, S. (2008). Weed and disease control in California- grown floricultural crops without Methyl Bromide soil fumigation (Abstr.) In: Proceedings of the 2008 Joint Annual Meeting, 5 – 9 October 2008

Lopez-Aranda, J. M., Romero, F., Montes, F., Medina, J. J., Miranda, L., De Los Santos, B., Vega, J. M., Paez, J. I., Dominguez, F., Lopez-Medina, J., Flores, F. (2001a). Chemical and Non-Chemical Alternatives to MB Fumigation of Soil for Strawberry. 2000-2001 Results. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions 2001. 5-9 November, 2001, San Diego, California, USA, pp. 40-1.

Lopez-Aranda, J. M., Medina, J. J., Miranda, L., De Los Santos, B., Dominguez, F., Sanchez-Vidal, M. D., Lopez-Medina, J., Flores, F. (2001b). Agronomic Behaviour of Strawberry Coming From Different Types of Soil Fumigation in Nurseries. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions 2001. 5-9 November, 2001, San Diego, California, USA, pp. 38-1.

Lopez-Aranda, J. M., Medina, J. J., Miranda, L., Dominguez, F. (2000). Three Years of Short-Term Alternatives To MB on Huelva Strawberries. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction 2000. 6-9 November, 2000, Orlando, Florida, USA, pp. 10-1.

Lopez-Aranda, J. M., Miranda, L., Romero, F., De Los Santos, B., Montes, F., Vega, J. M., Paez, J. I., Bascon, J., Medina, J. J. (2003). Alternatives to MB for Strawberry Production in Huelva (Spain). 2003 Results. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions 2003. November, 2003, San Diego, California, USA pp. 33-1.

López-Aranda J.M., Miranda L., Medina J.J., Soria C., Santos B.D.L., Romero F., Pérez-Jiménez R.M.,Talavera M., Fennimore S.A., Santos B.M. (2009a). Methyl bromide alternatives for high tunnel strawberry production in southern Spain.HortTechnology, 19, 187-192.

MBTOC (1995). United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee (MBTOC) 1994 Assessment of the Alternatives to Methyl Bromide. United Nations Environment Programme, Nairobi: 304pp.

MBTOC (1998). United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee (MBTOC) 1998 Assessment of the Alternatives to Methyl Bromide. United Nations Environment Programme, Nairobi: 358pp.

MBTOC (2002). United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee (MBTOC). 2002 Report of the Methyl Bromide Technical Options Committee. 2002 Assessment. United Nations Environment Programme, Nairobi.

MBTOC (2006). United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee (MBTOC). 2006 Report of the Methyl Bromide Technical Options Committee. 2006 Assessment. United Nations Environment Programme, Nairobi. 453pp.

MBTOC (2011). United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee (MBTOC). 2010 Report of the Methyl Bromide Technical Options Committee. 2006 Assessment. United Nations Environment Programme, Nairobi. 400pp.

Melgarejo, P., De Cal, A., Salto, T., Martinez-Beringola, M. L., Martinez-Treceno, A., Bardon, E., Palacios, J., Becerril, M., Medina, J. J., Galvez, J., Lopez-Aranda, J. M. (2001). Three Years of Results on Chemical Alternatives To Methyl Bromide For Strawberry Nurseries in Spain. In: Annual International Research

Conference on Methyl Bromide Alternatives and Emissions Reduction 2001. November 5 - 9, 2001, San Diego, California, USA. pp. 93-1.

Mitch, W. (2014). Destruction of methyl bromide on activated carbon using thiosulfate or electricity. . Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 4-6, 2014, Orlando, Florida, USA. Paper 38.

Montzka, S. and P. Fraser (2003) Controlled Substances and Other Gas Sources, Chapter 1 in: Scientific Assessment of Ozone Depletion, 2002, Global Ozone Research and Monitoring Project Report No. 47, Geneva, 1.1-1.83, WMO, Geneva, Switzerland, 2003.

Montzka, S., S. Reimann, A. Engel, K. Kruger, S. O'Doherty, W. Sturgess, D. Blake, M. Dorf, P. Fraser, L. Froidevaux, K. Jucks, K. Kreher, M. Kurylo, A. Mellencki, J. Miller, O.-J. Nielsen, V. Orkin, R. Prinn, R. Rhew, M. Santeee, A. Stohl & D. Verdonik (2011). Ozone-Depleting Substances (ODSs) and Related Chemicals, Chapter 1 in Scientific Assessment of Ozone Depletion: 2010, WMO Global Ozone Research and Monitoring Project – Report No. 52, 1.1-1.108.

Noling, J. W. and Gilreath, J. P. (2004). Use of virtually impermeable plastic mulches (VIF) in Florida strawberry. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, November 3-6, 2004, Orlando, Florida, USA. pp. 1-1.

Noling, J. W., Gilreath, J. P. and Rosskopf, E. R. (2001). Alternatives to Methyl Bromide Field Research Efforts For Nematode Control in Florida. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions , 5-9 November, 2001, San Diego, California, USA. pp. 14-1.

Nordiko 2015. Mobile Log Fumigant Recapture System. http://www.epa.govt.nz/search-databases/HSNO%20Application%20Register%20Documents/HRC08002_Nordiko%20Mobile%20Log%20Fumigant%20Recapture%20System.pdf. Accessed 14 February 2015.

Ntow, W. Ajwa H., Sullivan D., Hunzie1, J. (2009). Chloropicrin and Methyl Bromide Emissions Reduction by Using Totally Impermeable Film. In 'Annual International Research Conference on MB Alternatives and Emissions Reductions'Nov 10-13,San Diego, 2009.

Ou, L., Joy, P.J., Thomas, J.E.;,Hornsby, A.G. (1997). Stimulation of microbial degradation of MB in soil during oxidation of an ammonia fertilizer by nitrifiers. *Environmental Science and Technology.* 31, 717-722.

Papiernik, S. K., Yates,S. R., Dungan, R. S., Lesch, S. M., Zheng, W. and Guo M. (2004). Effect of surface tarp on emissions and distribution of drip-applied fumigants. *Environ. Sci. Technol.*, 38 (16), 4254–4262.

Porter, I. Banks, J., Mattner, S. and Fraser, P. (2010) Global phaseout of methyl bromide under the Montreal Protocol: implications for bioprotection, biosecurity and the ozone layer. In :*Challenges for Plant Protection in the 21st Century*. Gullino L. and Chet, E (eds). Springer Publishing, New York .

Qin R1, Gao S, Ajwa H, Sullivan D, Wang D, Hanson BD. (2011)Field evaluation of a new plastic film (vapor safe) to reduce fumigant emissions and improve distribution in soil. J Environ Qual. 40:1195-203

Qin, R., Daugovish, O., Gao, S., Hansen,B., Gerik, J., Ajwa, H. (2014).. Soil Fumigation applied through deep drip tapes in totally impermeable film in mulched raised-bed systems for strawberry production. 2014 ASHS Annual Conference

Rice, P., Anderson, T., Clink, J. and J. Coats. (1996). The influence of soil environment variables on the degradation and volatility of methyl bromide in soil. *Environ. Toxicol. Chem.* 15(10): 1723-1729.

Santos, B., J.P. Gilreath and T.N. Motis (2005). Managing nustedge stunt nematode in peppers with reduced Methyl Bromide plus chloropicrin rates under Virtually Impermeable Films. *HortTechnology* 15(3): 596 - 599

Santos, B.M. and J.P. Gilreath (2004). *Cyperus* spp. control with reduced Methyl Bromide rates under VIF in pepper. In: Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, Orlando, Florida, USA, 2004.

Swords, P. (2014). F.A.S.T. System : Fumigant Disposal and Scrubbing Treatment. . Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 4-6, 2014, Orlando, Florida, USA. Paper 39.

TEAP (2002). TEAP Task Force on Destruction Technologies Report. UNEP, Nairobi.

TEAP (2006). Report of the UNEP Technology and Economic Assessment Panel . September 2006. Evaluations of 2006 Critical Use Nominations for methyl bromide and related matters. UNEP: Nairobi. viii + 129 pp.

TEAP (2009). Report of the UNEP Technology and Economic Assessment Panel . September 2009. Evaluations of 2009 Critical Use Nominations for methyl bromide and related matters. UNEP: Nairobi. 103 pp.

Thomas, W. (1998). Feasibility of using gas impermeable tarps to reduce MB emissions associated with soil fumigation in the United States. *United States Environmental Protection Agency Report*. Jan 26, 1998.

USA (2009). Methyl bromide Quarantine and Preshipment interim management strategy. October 30, 2009. 33pp.

Vasireddy, S. (2014). Enhanced catalysts for combustion of CH3Br: MOX-CEO2 (M= Mn, Co). . Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. November 4-6, 2014, Orlando, Florida, USA. Paper 40.

Villahoz, M,D., Garza, F., Barrows, P. and Sanjurjo, M. (2008). TIF (Totally Impermeable film). An Innovative Film for Much, Broadcast Fumigation and greenhouses in Agriculture. In: Annual International Research Conference on MB Alternatives and Emissions Reductions. Orlando, Florida, USA, November 11-14, 2008

Wang, D., Yates, S., Gan, J. and J. Knuteson. (1999). Atmospheric volatilization of methyl bromide, 1,3-dichloropropene, and propargyl bromide through two Plastic films: transfer coefficient and temperature effect. *Atmospheric Environment.* 33: 401-407.

Wang, D.; Yates, S.R.; Ernst, F.F.; Gan, J.; Gao, F.; Becker, J.O. (1997a). MB emission reduction with optimized field management practices, *Environmental Science and Technology.* 31: 3017-3022.

Wang, D.; Yates, S.R.; Ernst, F.F.; Gan, J.; Jury, W.A. (1997b). Reducing MB emission with a high barrier plastic film and reduced dosage. *Environmental Science and Technology*. 31: 3686-3691.

WMO (World Meteorological Organization) (2003). Scientific Assessment of Ozone Depletion: 2002, United Nations Environment Programme (UNEP), Nairobi, Kenya, 2003

WMO (2007) (World Meteorological Organization). Scientific Assessment of Ozone Depletion: 2006, United Nations Environment Programme (UNEP), Nairobi, Kenya.

WMO (2011) (World Meteorological Organization). Scientific Assessment of Ozone Depletion: 2010, United Nations Environment Programme (UNEP), Nairobi, Kenya.

WMO (2015) (World Meteorological Organization). Scientific Assessment of Ozone Depletion: 2014, United Nations Environment Programme (UNEP), Nairobi, Kenya

Yates, S.R. (2005). Reducing bystander exposure by emission reduction. Annual International Research Conference on MB Alternatives and Emissions Reductions. Oct 31 - Nov 3, 2005. San Diego, California, USA

Yates, S. (2006). Developing a simple low-cost approach for evaluating emission reduction methods. In: Annual International Research Conference on MB Alternatives and Emissions Reductions. Orlando, Florida, USA, November 3 – 6, 2006

Yates, S, Papierknik S., Chellemi D, Wang D, Gao S, Hanson B, Ajwa H, Browne G, Kluepfel D. (2009). Update of film permeability measurements for USDA-ARS area-wide research project. In ‘Annual International Research Conference on MB Alternatives and Emissions Reductions’Nov 10-13,San Diego, 2009.

Yates, S. R., Gan, J., Wang, D and Ernst, F.F. (1996). MB emissions from agricultural fields. Bare-soil deep injection. *Environmental Science and Technology,* 31: 1136-1143.

Yates, S. R., Wang, D., Gan, J. and F.F. Ernst. (1998). Minimizing methyl bromide emissions from soil fumigation. *Geophysical Research Letters,* 25(10): 1633-1636.

9

Chapter 9. Economic issues

9.1. Introduction

During CUN evaluations, MBTOC assesses the financial feasibility of alternatives available to the Party (Decision IX/6), because an alternative may be considered technically feasible, but may not be economically feasible. Measurement of the economic implications of the use of methyl bromide or an alternative can in most cases be done satisfactorily by means of a partial budget analysis, a practical tool to compare alternative production practices. In the case of a Soils nomination, the analysis consists of measuring the costs of methyl bromide treatment and the revenues of the relevant crop when methyl bromide is used, as well as the treatment costs and revenues for technically feasible alternatives. Only the costs that actually change as a result of the use of the alternative need be considered, hence the name partial budgeting. So, for example, if tractor use increases as a result of the use of the alternative, this change in cost needs to be taken into account. If the use of fertilizer or any other input remains unchanged, however, this item can then be ignored.

The main advantage of partial budgeting is its simplicity. However, because prices change continuously and randomly (i.e. they are stochastic), the results are often unstable, even in the short term. In those cases where stochastic prices are thought to influence decisions, economists typically assess prices using more stable estimates of supply and demand, typically in the form of a partial equilibrium analysis. This is based on the assumption, among others, that changes in one market do not have spillover effects on all other markets. Again, this assumption is made for the sake of simplicity, but is not always realistic. There are circumstances where a general equilibrium analysis would be required, namely where a change in prices or another variable such as supply or demand has knock-on effects on other markets. So, for example, as methyl bromide use is phased out it will no longer be readily available, so that it’s price will be expected to rise and this increase will increase the speed of adoption of alternatives.

The analyses described thus far all use current prices to measure the economic effects of using methyl bromide and it's alternatives. However, prices may be distorted through government action. For example, high tariffs against imports of chloropicrin will distort its domestic price and thereby influence the economics of the use of methyl bromide and it's alternatives. When such price distortions are thought to be dominant, an economic analysis using ‘shadow’ prices may be called for. In this event, economists try and establish what the prices would have been in the absence of the distortion in question.

Finally, conventional economic analysis only considers the ‘visible’ differences in outcome as a result of the use of methyl bromide or it's alternatives. However, economists recognize the existence of ‘externalities’, which arise when the costs or benefits of an action are not all taken into account by the relevant decision maker. For example, the full benefits of the phase-out of methyl bromide are not taken into account in a partial budget analysis, where only changes in the user's revenue are measured while the benefits to society of less ozone depletion are ignored. Economists can however include these benefits, but first need to put a monetary value to the benefit, using surrogate prices measured with techniques such as 'willingness to pay'.

It is evident that the techniques discussed here differ in their need for more and more information. For this reason, it does not make sense to use techniques that are not necessary. This is reflected in the state of the published literature on the economic feasibility of alternatives to methyl bromide. The literature is dominated by partial budgeting: 16 of the 20 articles published in the peer reviewed and 'grey' literature over the period 2010 to 2014 use this technique[6]. This review focuses on the other four publications. Furthermore, a case study of the economics of moving the production of strawberry runners to soilless cultures in different countries is planned to illustrate the factors that need to be taken into account in the process of establishing when an alternative is technically feasible. This case study will be provided at a later date.

9.2. Other techniques

As noted in previous Assessment and Progress Reports, **Norman (2005)** provided the most comprehensive ex ante analysis of the impact of the methyl bromide phase-out on the California strawberry industry. In a follow-up study, **Mayfield and Norman (2012)** point out correctly that it is impossible to advise Parties on the economic feasibility or otherwise of methyl bromide and its alternatives because they (the Parties) have yet to arrive at a consensus definition of what standard must be met. At best it could be argued (as MBTOC has proposed) that it cannot mean that users of methyl bromide do not have to change their production practices or that there are no changes in costs (p 93).

The authors point out that the data on economic feasibility are not plausible given that the adoption of alternatives has increased, that strawberry yields have increased, and that the acreage under strawberries has increased (Mayfield and Norman, 2012: 99). In their view farmers are likely to have modified their production practices (e.g. input substitution, different weeding methods) and to have learned while implementing new procedures. Furthermore, even if costs increase, some of this cost may be shifted to consumers given the particular relative elasticity of demand and of supply, as shown in Norman (2005).

Larsen (2014) has conducted a political economy analysis that rests on the observation that farm workers have relatively little political and economic power (her argument is based on the California strawberry industry, but is generalizable to other places where farm workers share the same lack of influence). This disables them from protesting against the use of methyl bromide, which has the effect of making alternatives more expensive. As growers cannot change the circumstances (including wages) of workers unilaterally because of competition, it will be up to consumers to take up these and similar causes.

Niu *et al.* (2013) argue that Integrated pest management (IPM) is an alternative to fumigation of food processing facilities, and has the added benefit that it may reduce insecticide resistance, improve worker safety, and reduce environmental and consumer concerns about pesticide residuals. They use a Geographic Information System (GIS) to measure both the treatment costs as well as the costs of failing to control insects.

[6] These are provided in the reference list.

Petersen *et al.* (2013) propose a method for assessing the actual cost of sanitary and phytosanitary regulations for 47 fresh fruit and vegetable product imports into the USA from 89 exporting countries over the period 1996–2008. Importantly, the results confirm that these measures generally reduce trade, but that this effect is weakened over time as exporters accumulate experience, and it eventually vanishes.

9.3. References

Abou-Zeid N.M., Mahmoud N.A., Khalil A E. (2011). Efficiency of certain methyl bromide alternatives and their economical feasibility on tomato infected with root-knot nematode and fungi under field condition in Egypt. 4eme Conference Internationale sur les Methodes Alternatives en Protection des Cultures. Evolution des cadres reglementaires europeen et francais. Nouveaux moyens et strategies Innovantes, Nouveau Siecle, Lille, France, 8-10 mars 2011. 606-613.

Bangarwa S.K., Norsworthy J.K., Rainey R.L., Gbur E. E. (2010). Economic returns in plasticulture tomato production from crucifer cover crops as a methyl bromide alternative for weed management. *Hort. Technology* 20: 764.

Barrett C.E., Zhao X., Hodges A.W. (2012). Cost benefit analysis of using grafted transplants for root-knot nematode management in organic heirloom tomato production. *Hort. Technology* 22: 252

Carroll C., Carter C., Goodhue R., C.-Y. Cynthia Lin, Subbarao K. (2013). Bio economic modelling of an imported disease in California lettuce. In: Joint Annual Meeting of the Agricultural & Applied Economics Association AAEA & CAES, Washington, D.C., August 4-6, 2013.

Devkota P., Norsworthy J.K., Rainey R. (2013). Efficacy and economics of herbicide programs compared to methyl bromide for weed control in polyethylene-mulched tomato. *Weed Technology*: 27: 580.

Djidonou D., Zhifeng G., Zhao X. (2013). Economic analysis of grafted tomato production in sandy soils in northern Florida. *Hort. Technology* 23: 613

Ferrer M.C., Fonsah R., Escalante E.G., Cesar L. (2011). Risk-efficient fumigant-mulching system alternatives for bell pepper production. *Journal of the American Society of Farm Managers and Rural Appraisers*

Fonsah, E.G., Ferrer M.C., Escalante C., Culpepper S. (2012). Financial analysis of methyl bromide and mulch alternatives for bell pepper in Georgia. In: UGA Cooperative Extension Bulletin 1411

Larsen J. (2014). Farmworkers and strawberry cultivation in Oxnard, California: a political economy approach. In: *Scripps Senior Theses.* Paper 502. Available at http://scholarship.claremont.edu/scripps_theses/502

Mayfield E.N., Norman C.S. (2012). Moving away from methyl bromide: Political economy of pesticide transition for California strawberries since 2004. *Journal of Environmental* Management: 106: 93

Niu, L., Adam B.D., Arthur, F., Campbell, J. (2013). A GIS approach to measuring economic costs of integrated pest management tools in rice processing facilities. In: AAAE Annual Meeting, August 4-6, 2013, Washington, D.C.

Norman, Catherine S., 2005, Potential impacts of imposing methyl bromide phaseout on US strawberry growers: a case study of a nomination for a critical use exemption under the Montreal Protocol, Journal of Environmental Management 75: 167–176

Peterson E., Grant J., Roberts D., Karov V. (2013). Evaluating the trade restrictiveness of phytosanitary measures on U.S. fresh fruit and vegetable imports. *American. Journal of Agricultural Economics* 95: 842.

Rivard C.L., Sydorovych O., O'Connell, S. Peet M.M, Louws F.J. (2010). An economic analysis of two grafted tomato transplant production systems in the United States. *Hort Technology* 20: 794

Samtani, J.B., Gilbert C., Weber J.B., Subbarao, K.V., Goodhue R.E., Fennimore S.A. (2012). Effect of steam and solarisation treatments on pest control, strawberry yield, and economic returns relative to methyl bromide fumigation. *HortScience* 47: 64.

Sayin B., Celikyurt M.A., Yilmaz S., Celik, I. (2010). Economic evaluation of chemical and non-chemical soil disinfestation applications for tomato production in Turkey. *Acta Horticulturae* 883: 91

Tohamy A., Abou-Zeid N.M., Khalil M.S. (2012). Vegetable grafting: An alternative method for soil fumigation with methyl bromide—The Egyptian experience In: Conference of the American Phytopathological Society poster session. Available at http://www.apsnet.org/meetings/Documents/2012_Meeting_Abstracts/aps12abP297.htm

Walters T., Particka M., Zasada I., Pinkerton J.N. (2011). Productivity and economics of methyl bromide alternatives for raspberry nursery. Proc. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. http://www.mbao.org/2011/Proceedings/29WaltersT.pdf

Waterfield G., Zilberman D. (2012). Pest management in food systems: an economic perspective. *Annual Review of Environment and Resources* 37: 223.

Xiang C., Zhengfei G., Vallad G.E. (2014). An economic analysis of fumigation alternatives, the methyl bromide ban, and its implication: evidence from the Florida tomato industry. In: Annual Meeting Agricultural & Applied Economics Association, Minneapolis, MN, July 27- 29, 2014.

Annex 1

Case Studies

1. Alternatives for preplant (soils) uses in Article 5 Parties

The projects have provided useful experiences on the substitution of MB and the adoption of alternatives at the commercial level. Following are four examples of successful phase out of MB in economically important sectors for Article 5 countries.

Case Study 1. Alternatives to MB for floriculture in Brazil

Initial situation

In Brazil, the ornamental plant and cut flowers sector is an active, fast-growing agribusiness geared at both export and internal markets, with an estimated value of US$ 2 billion/year. Diverse environmental conditions allow production of many different species throughout the year in open field or greenhouses, but soil borne plant pathogens can cause heavy economic losses. MB was thus used in the past for disinfecting substrates and growing disease-free seedlings, and also for pre-plant soil fumigation. In 2002, the Government of Brazil issued an administrative rule establishing a phase-out schedule of controlled uses of MB by type of crop with a complete ban for all controlled uses by 2007.

Description of the alternative (s) implemented

Non-chemical alternatives were selected to replace MB in floriculture. This included a solar collector for treating substrates used as potting mixes, steam treatment for soil, biological control and organic matter amendments.
The solar collector was developed to disinfest substrate using solar radiation, (Ghini 2014).

The equipment comprises six aluminum tubes (15-cm diameter) placed in parallel rows in a wooden box (1.5m×1.0m×0.3 m), covered with transparent plastic film. Soil or substrates are placed inside the tubes through the upper hatch, during the early morning, and recovered through the lower hatch, after 24 hours of treatment in a sunny day. After treatment, the substrate can be used immediately or can be stored. In Brazil, this equipment can be used throughout the year. Temperatures above 70 C are easily obtained inside the aluminum tubes during sunny days, which result in the control of several soil-borne plant pathogens, including species of *Fusarium, Pythium, Rhizoctonia, Sclerotium, Sclerotinia, Phytophthora, Meloidogyne and Ralstonia* (Ghini *et al*., 2007; Ghini 2014).

Steam was the alternative of choice for the treatment of soil. A mobile steam injector was adapted in order to guarantee homogeneous application of the steam.
Biological control consisting of 4 commercial products containing *Trichoderma* spp. and two with *Paecilomyces lilacinus* are registered in Brazil for soil treatment to control soil borne pathogens (Bettiol *et al*., 2014).

Several different types of organic matter are used to induce soil or substrate supressiveness alone or associated with biological agents for flower production in Brazil. The main organic matters are compost tea, poultry manure, chicken litter, cattle manure and shrimp peeling.

Actions for alternative (s) implementation

UNIDO and the Ministries of the Agriculture and Environment of Brazil implemented a project jointly to totally phase-out MB in floriculture. The growers' associations received a kit comprising a boiler powered by eucalyptus wood (with capacity of 600 kg / h of steam) and a mobile steam injector for soil. A total of 28 boilers, 27 mobile steam injectors, and 823 solar collectors were donated to the associations on a rotation basis according to the reported consumption of MB in the period 2002 - 2006. A training program on alternative technologies was included within the project, and farmers and private companies were encouraged to implement the use of biological control agents and organic amendments. Neither solar collectors nor steam require regulatory approval.

Crop yields, and control of soil borne pests

The solar collector provides the same level of control as MB, and has no impact on occupational health and environmental contamination. Another advantage is the increased growth of plants and better flower quality. The treatment does not sterilize the substrate, and thus helps prevent reinfestation, since beneficial microorganisms are preserved. Disinfestation with steam does not provide residual protection, so this option needs to be implemented within an IPM approach including biological agents and organic amendments, to keep diseases controlled during the production period.

Costs and profitability

For Brazilian growers, the solar collector was economically cost effective (cost being less than MB fumigation). It should be considered that this is basically a one-time expense. Soil steaming is expensive, but farmers in Brazil find it to be a cost-effective alternative, particularly because they are able to use of wood instead of gasoline or diesel fuel.

Current situation

Farmers are successfully using the alternatives for MB treatment of soil, and are currently disseminating the technologies to other farmers. Solar collectors offer an inexpensive, efficient and safe system for the production of healthy seedlings, besides being easy to build and operate. The MB phase-out was not only a matter of protecting the ozone layer, but also an opportunity for growers to adopt non-chemical technologies, making them more competitive in the international market.

References

Bettiol, W., Rivera, M.C., Mondino, P., Montealegre, J.R., Colmenárez, Y.C. (2014). Control biológico de enfermidades de plantas en America Latina y el Caribe. Facultá de Agronomia, Montevideo. Uruguay. 404 p. http://portal.fagro.edu.uy/index.php/intensific-agr/file/367-control-biologico-de-enfermedades-de-plantas-en-america-latina-y-el-caribe.html

Ghini R.; Patrício F.R.A., Almeida I.M.G. (2007) Control of *Ralstonia solanacearum* in tomato potting medium by the use of a solar collector. *Australasian Plant Disease Notes* 2, 77-78.

Ghini, R. Climate change and increasing challenges for effective soil disinfestation. *Acta Hort.* 1044: 447-454.

Provided by Raquel Ghini, Embrapa, Brazil, MBTOC Member

Case Study 2. Alternatives to methyl bromide in the strawberry fruit, banana and cut flower sectors of Morocco: New developments, current situation and future challenges

Chtaina and Besri (2006) published a case study on alternatives to MB in the strawberry fruit, banana and cut flower sectors. Since that date, more research has been conducted and new developments on alternatives are available, which form the focus of this case study.

Initial situation

The government of Morocco committed to early MB phase-out by 2008, of 259 tonnes of MB used in the strawberry sector, 60 tonnes used in the banana sector and 42 tonnes in the cut flower sector. The phase-out program was financed by two MLF investment projects managed by UNIDO as implementing agency. This has led to a gradual elimination of MB during the period 2003-2008.

Description of the implemented alternatives

The Department of Plant Pathology of the Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco was in charge of the implementation of the projects in mention. Research conducted by the department staff members and its graduate students and allowed for the development of technically and economically feasible alternatives to MB.

- *Strawberry fruit sector*

Drip applied metham sodium (MS) has been used successfully to control fungi (*Rhizoctonia solani, Verticillium dahliae, Phytophthora cactorum*) and weeds (more than 40 species e.g. *Cynodon dactylon, Chenopodium* sp, *Amaranthus* sp.). MS at a dosage of 510 g/l of active ingredient is injected at a rate of 200 to 250 g /m2. During the past 7 years, MS has been the only product used by the farmers in the strawberry sector, showing high efficacy and economic feasibility. In addition, it does not require any modification of the cropping system. Currently, about 2000 tons of MS are used annually in the strawberry sector. Yields and fruit quality are considered equivalent to those achieved with MB in the past (Chtaina and Besri, 2006; Chtaina, 2008a).
DMDS is now registered in Morocco and initial research results are very promising (unpublished data). Soil less culture technology using various substrates has been developed and its use is increasing (unpublished data).

- *Protected banana sector*

Between 2002 and 2004, an alternative combining soil solarisation and drip fumigation with 1,3-D as a broadcast or row treatment was developed to control banana nematodes (*Meloidogyne javanica, Helicotylenchus multicincthus*) (Chtaina, 2005). 1,3-D is injected at a dosage of 20 ml/m2. This method requires the installation of drip tapes connected to the main pipeline independently of the existing sprinkler irrigation system used in banana greenhouses. The major disadvantage of this method is the time and labor needed for installing drip irrigation and plastic mulch prior to the treatment (Chtaina, 2005), which has led to nil use of this alternative. At present, nematode control in the banana sector relies on nematicides applied after planting e.g. fenamiphos, cadusafos, oxamyl and fosthiazate in granular or liquid formulations. DMDS has been registered on banana in 2012 and is currently tested.

- Cut flower sector

In the cut flower sector, the situation is similar to the one described for the banana sector. Solarisation combined with drip application of 1,3-D/Pic, controls *Fusarium* spp, *Rhizoctonia* spp and nematodes (*Heterodera sachtii* and *Meloidogyne* spp.). This alternative does not require modifications of the cropping system since the existing drip irrigation system can be used to apply the fumigant (Chtaina, 2008b).

Costs of the alternatives

Table 1: Cost of the different listed alternatives (2014)

MB and alternatives	Crop	Total application cost US$/ 1000 m^2
MB	All	640 (1)
Metham sodium at high dosage (127, 5 g /m^2 of active ingredient) or 250 ml / m^2 of commercial product of 510g/l ai.)	Strawberries	250 (2)
Granular (G) or liquid post plantation nematicides (1 to 2 applications) - phenamiphos (Nemacur 10G): 50g/plant - cadusafos (Rugby à 10 G) : 20g /plant - Fosthiazate (Memathorin 10 G: 20g /plant	Banana	30 Per application
Solarisation + 1,3-D 65%+ chloropicrin 35% at. 450 kg /Ha	Cut flowers	350 (1)

(1) Broad acre application. (2) Row acre application

Regulatory agency acceptance

All chemical alternatives are registered in Morocco. New MS and 1,3 D formulations are registered. However, Morocco is confronted to the European pesticide regulatory controls, which may have serious repercussions on crops particularly where nematodes are of great importance such as in cut flower, tomato, bean, cucumber, melon, etc.

Future challenges

Morocco will face at least two major challenges in the future:

In the strawberry sector: Repeated applications of MS may lead to accelerated fumigant degradation, and a management strategy to prevent this problem is required (Triky-Dotan *et al*., 2009).

In the cut flower and banana sector: 1,3-D is the main alternative used, especially for nematode control. However, in the EU, 1,3-D use is being restricted under various regulations. The situation is completely different in Morocco. In this country, only 1800 t of 1,3-D are used in the region of Agadir. In addition, the piezometric groundwater level is at least 200 meters.

References

Chtaina N., 2005. Les fumigants nematicides à base du 1,3 dichloropropène, comme alternative au bromure de méthyle sur bananier. Pack info N° 24: 19-20

Chtaina N., M. Besri, 2006. Case Study 26. Morocco-Phase out of methyl bromide in the strawberry, banana and cut flower in Morocco.2006 assessment report of the methyl bromide technical option committee (MBTOC). UNEP, 424-427, 453 pp.

Chtaina N., 2008a. Phase out of methyl bromide in soil fumigation in strawberry production. UNIDO project MP/MOR/00/164 contract (ONUDI/ Institute of Agronomy and Veterinary medicine, Rabat Morocco) N° 2001/261. Final report, 2008. pp 80

Chtaina N., 2008b.Phase out of methyl bromide in the cut flower and banana production. UNIDO project TF/MOR/00/001 contract (ONUDI/ Institute of Agronomy and Veterinary medicine, Rabat Morocco) N° 2002/089. Final report, December 2008. pp 64

Triky-Dotan S., Austerweil M., Steiner B., Peretz-Alon Y., Katan J., and Gamliel A., 2009. Accelerated Degradation of Metham sodium in Soil and Consequences for Root-Disease Management Phytopathology Vol. 99, No. 4, 2009: 362-368

Provided by Professor Noureddine Chtaina n.chtaina@iav.ac.ma, Project manager, UNIDO MB projects, and Prof. Mohammed Besri m.besri@iav.ac.ma, MBTOC cochair, Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco

Case Study 3. Adoption of alternatives to methyl bromide in the vegetable sector in Turkey

Vegetable Sector in Turkey

Total vegetable production of Turkey is around 28,5 million tons with protected vegetables comprising 4,7 million tons (GTHB, 2014). Tomato is the most important crop in both open field and protected production

Table 1. Vegetable production in Turkey in 2013

Vegetables	Production (tons)
Tomato	11,820,000
Watermelon	3,887,324
Pepper	2,159,348
Onion	2,058,342
Cucumber	1,754,613
Melon	1,699,550
Eggplant	826, 941
Other Vegetables	4,242,000
Total	28,448,118

There are approximately 150,000 protected vegetable growers in Turkey (Titiz 2004, Yılmaz *et al*., 2008). The vegetable sector has grown rapidly and in 2013, a total export value of US $1,105 million was reported (AKİB, 2013).

Methyl bromide use in Turkey

MB was mainly used to control soil borne pathogens and nematodes (Table 2) prevailing in protected vegetable production (tomato, pepper, cucumber, eggplant). A consumption of 487.6 tonnes of MB was reported for the Turkish vegetable sector in 2000.

Table 2. Main soil borne pathogens prevailing in Turkey

Host plant	Key pathogens	Secondary pathogens
Tomato	*Meloidogyne* spp., *Fusarium ox*. f.sp. *radicis-lycopersici, Fusarium oxysporum.* f.sp. *lycopersici*	Sclerotinina sclerotiorum
Cucumber	*Meloidogyne* spp.,	Verticillium spp.
Pepper	*Meloidogyne* spp., *Fusarium solani*, *Phytophthora capsici*	Sclerotinia sclerotiorum
Eggplant	*Meloidogyne* spp. *Fusarium oxysporum*. f.sp. *melonganea*, *Verticillium* spp.	-

Two demonstration projects and one investment project on alternatives to MB were implemented with funding from the MLF (Öztürk *et al*., 2002), and led to complete phase-out of MB for controlled uses in 2006 (Yılmaz *et al*., 2006 (Table 3).

Table 3. Methyl bromide phase-out schedule in agricultural sectors in Turkey

Horticulture and Cut-flower Sub-Sectors				**Total Methyl Bromide Consumption***	
Years	Expected Reduction (ODP tonnes)	Consumption (ODP tonnes)	Consumption (tonnes)	Consumption (ODP tonnes)	Consumption (tonnes)
2000	0.0	292.2	487.6	342.6	571.0
2001	0.0	292.2	487.6	332.6	554.3
2002	29.3	263.6	439.3	293.4	489.0
2003	58.6	204.7	341.1	225.4	375.7
2004	58.6	146.1	243.5	167.4	279.0
2005	87.9	58.2	97.0	78.4	130.6
2006	58.6	00.0	00.0	20.4	34.0

* Including horticulture and flower sub-sectors. Consumption for QPS and lab uses not included

Actions for Replacing Methyl Bromide

To support the early phase-out commitment, the following actions were taken:

Legislative actions: The Ozone Office (MEUD) coordinated the phase-out and the General Directorate of Food and Control (MFAL), coordinated MB imports in accordance with the agreed MB phase-out schedule. Agricultural practices and chemical uses were brought into compliance with EU regulations. Imported MB is presently sold only by quarantine services located in Istanbul, Izmir, and Mersin provinces. The MB phase-out action plan and a new regulation "Phasing out Agricultural Uses of MB" was published in the Official Gazette on the 23rd of June 2000. Sales and import of MB were defined by regulation 25427/2004.

Project Actions: Four projects were carried out to phase out MB in the horticulture sector of Turkey (Yılmaz *et al*., 2006) implemented by UNIDO and the World Bank.

Research Actions: The 4 projects considered chemical and non-chemical alternatives. Steam was very efficient but too costly to apply, bio-fumigation (chicken manure) resulted in a salinity problem (Öztürk *et al*., 2002). Other technologies included solarisation (S), S+chemicals [metham sodium (MS), dazomet (D) and 1,3-D], grafting, soilless culture and bio-fumigation. A strong IPM component was included.

Training Actions: Training was an integral part of the phase-out projects and included workshops, grower and technical personnel meetings, field visits, direct trainings in the field, national and international training programs, radio and TV programs and others. Nearly 1,000 technical assistants working in extension services, research institutes and the private sector were trained. A total of 12,087 growers were visited and directly trained on IPM, cultivation techniques (irrigation, fertilization etc.), soilless culture and bio-control agents. Project staff and leading growers participated in study tours in Austria, China, Colombia, Cuba, Netherlands, Italy and Spain where they increased their knowledge and experience on vegetable and cut flower production, IPM and MB alternatives. Approximately 77,000 brochures on 27 subjects, 2,000 posters and billboards, 12,000 books related to good agricultural practices (GAP) implementations on 5 different vegetables and 9 reports were published and distributed to relevant stakeholders (Yılmaz et al., 2006, 2008).

Good Agricultural Practices (GAP): Project staff identified 2,368 leading greenhouse growers who were then trained on GAP, and supported with goods, equipment and technical information from the project budget. Selected greenhouses were regularly visited by the project personnel between 2004 and 2006. Growers were trained on keeping records on pests, diseases, climate control, soil management, growing techniques etc. Eight books were published related to GAP implementation in vegetables. (Yılmaz et al., 2006, 2008).

Extension Actions: Trained extension staffs from Antalya, Adana, Mersin, İzmir, Isparta and Muğla Provinces were instrumental for disseminating knowledge and expertise to growers and played a very important role in both the demonstration and phase-out projects (Yılmaz et al., 2006).

Description of Alternatives Implemented

Chemical and non-chemical alternatives were used to replace MB in the Turkish horticulture sector. Solarisation alone or in combination with low dosages of chemicals, bio-fumigation, grafting, soilless culture and steaming were very successful especially in the vegetable sector to control soilborne diseases, nematodes and weeds, with each of these options showing advantages and disadvantages.

Solarisation (S) alone or combined with low dosages of chemicals (S + 1,3-D for nematode control, S + MS or Dazomet or Methyl iodide for soil-borne diseases control) was effective to control soilborne pathogens in the vegetable sector under the favorable climatic conditions of the Mediterranean Region (Yilmaz et al., 2007-2008). Nevertheless, cancelling of 1,3-D registration due to the environmental concerns and the high cost of Methyl iodide limited their use in Turkey. Year-round solarisation in conjunction with VIF plastic provided much better results than solarisation in the summer only, providing very good yield and quality in eggplant, melon and cucumber (Yilmaz et. al., 2011).
Bio-fumigation was efficiently applied in conjunction with solarisation, but availability and cost of fresh manure generally limited its use (Öztürk et al., 2002; Yılmaz et al., 2006).
Grafting adoption expanded rapidly since 1998 in the vegetable sector, reaching 150 million grafted plants by 2013 (personal communications with grafted seedling companies). It is a viable alternative to MB to control soil borne pathogens and delivers high quality yields especially in watermelon, eggplant and tomato (Yilmaz et. al., 2011; Karaca et al., 2012). This technology was also used in pepper and melon, however some compatibility problems between rootstocks and scions persist.

Soil-less culture is feasible for vegetables and cut flower. However it is a technically demanding option for growers with high initial costs. In spite of this, its use has increased in recent years.

Steam turned out to be too costly for horticulture production due to high fuel prices and was not a viable alternative. However, it might be used to steam seedling and soilless culture beds (Yılmaz et al. 2006, 2008).

Lessons learned

New techniques such as soilless culture, grafting, steam, compost and chemicals as well as novel growing techniques were introduced and accepted by Turkish growers. Solarisation was the cheapest and most effective alternative when combined with some chemicals. The importance of monitoring and traceability of crops and pests was understood by growers and the usefulness of IPM and GAP in vegetable sector was demonstrated in model greenhouses to project stakeholders. Strong coordination and collaboration among academicians, researchers, extension staff, growers, companies, consultants, dealers, and policymakers was achieved during the project. MB use for soil was completely and irreversibly phased out in Turkey without putting any burden on growers.

References

AKIB 2013. Sektörel Bazında Aralık 2013 İhracat Verileri. http://www.akib.org.tr/tr/ihracat-ihracat-istatistikleri.html

GTHB, 2014. T.C. Gida Tarim Hayvancilik Bakanligi, Bitkisel Uretim Verileri. http://www.tarim.gov.tr/sgb/Belgeler/SagMenuVeriler/BUGEM.pdf

Karaca, F., Yetişir; H., Solmaz İ., ElifÇandır, E., Kurt, Ş., Nebahat Sarı, N., and Güler Z. 2012. Rootstock potential of Turkish *Lagenariasiceraria* germplasm for watermelon: plant growth, yield, and quality. Turkish J Agriculture and Forestry 36:1101-1716

Özalp, R. and Aktaş, A., (2008). Türkiye ve Antalya'da sebzeciliğin genel durumu. *Tarımın Sesi Dergisi,* 17:15-18. Antalya.

Ozturk, A.; Yilmaz, S.; Kececi, M.; Unlu, A.; Deviren, A.; Ozcelik, A.; Cetinkaya, S.; Cevri, H.; Akkaya, F. and Ozkan, C.F. (2002). Alternatives to methyl bromide for tomato and cucumber production in Turkey. *Proceeding of Alternatives to Methyl Bromide*. Sevilla, Spain. pp. 194-199.

Titiz, Ş. (2004). Modern Seracılık, Yatırımcıya Yol Haritası. Antalya Sanayici ve İş adamları Derneği.Retma Yayıncılık, Antalya (Modern Greenhouses, Road map for Investors. Association of Antalya Industrialists and Businessmen. Retma Publication, Antalya.)

TUİK (2009). Turkey Statistic Foundation (TUİK) (State Institute of Statistics). Agricultural structure and production. Publication no. 2895., Ankara, Turkey.

Yilmaz S, Celik I, Zengin S. (2011). Combining effects of soil solarisation and grafting on plant yield and soil-borne pathogens in cucumber. *International Journal of Plant Production* (2011) 5(1): 95-104

Yilmaz, S., Fırat, A.F., Mutlu, N. and Sürmeli, N. (2005). Recent Developments and Constrains Confronting Vegetable Production Systems in Turkey.

Yilmaz, S., Gocmen, M., Ünlü, A., Aydinşakir, K., Mutlu, N., Baysal, Ö., Sayın, B., Celikyurt, M.A., Fırat, A.F., Çelik, İ. Aktaş, A., Öztop, A., Zengin, S., Devran, Z. and Tekşam, İ., (2008). Phasing out of methyl bromide in Turkey: Final Report, ISBN 9789754072549, 156 p., Antalya.

Yilmaz, S., Ünlü, A., Göçmen, M., Aydinşakir, K., Sayin, B., Kazas, S., Çelikyurt, M.A., Aktaş, A. and Zengin, S (2007). Alternatives to methyl bromide for cut flowers in Turkey. In: Annual International Conference on Methyl Bromide Alternatives and Emission Reductions. San Diego, CA, USA pp. 48-1-3.

Yilmaz, S., Ünlü, A., Gocmen, M., Mutlu, N., Aydinşakir, K., Fırat, A.F., Kuzgun, M., Celikyurt, M.A., Sayın, B. and Çelik, İ. (2006). Phase out of methyl bromide for soil fumigation in protected horticulture and cut flower production in Turkey. Final Report, 2006. Antalya, Turkey.

Prepared by S. Yilmaz (MBTOC member) and K. Aydinsakir

Case Study 4. Phasing out MB in tomato and cucumber by combining resistant cultivars, grafting, avermectin and soil fumigants in China

Initial situation

Cucumber and tomato are the main vegetables produced in China. About 1,157,000 ha are cultivated with cucumbers with a total yield of nearly 52 million tonnes. The area grown with tomatoes is 949,500 ha with total yield of about 5 million tonnes (Ministry of Agriculture, 2013). Both crops are grown both in protected and open field environments, but greenhouse cultivation is becoming increasingly important.

Cucumbers and tomatoes are grown in fixed plastic tunnels where it is difficult to rotate with low value crops like wheat, maize or cotton. The conventional rotation model is tomato (or cucumber in autumn), followed by a short-term vegetable such as leaf oil rape in winter and then cucumber (or tomato) in spring. The occurrence of nematodes and soil-borne diseases has become more and more severe, and seriously affect yield and quality after 3-5 years cultivation.

MB was mainly used in cucumber and tomato in the Shandong and Hebei Provinces, in the Beijing and Tianjing municipalities. The total MB consumption in these sectors was about 55 tonnes. MB was applied at rates of 40-50 g/m2to control root knot nematodes (Meloidogyne spp), damping off *(Rhizoctonia* sp. and *Pythium* sp.), *Fusarium* wilt (*Fusarium oxysporum* f.sp. *lycopersici*) and *Phytophthora* spp.

Chemical alternatives, such as dazomet, metham sodium, chloropicrin, Avermectin, sulfuryl fluoride are registered in China but 1,3-D is not registered.

Description of the alternative (s) implemented

Cucumber grafting is an old technology in China, used by many farmers. The rootstock is pumpkin with white or black seeds, resistant to *Fusarium oxysporum* f.sp. *lycopersici* and with some tolerance to nematodes. Resistant tomato cultivars contain the Mi gene and are resistant to rootknot nematodes. Farmers are using grafting without any change in the cropping system.

Avermectins are produced by Streptomyces avermitilis and have broad-spectrum activity against a large number of nematodes and arthropods so are widely used in veterinary and agriculture.(Putter, 1981; Sasser et al., 1982; Carabedian and Gundy, 1983; Bull et al., 1984; Cao, 1994; Cao, 1999).When nematodes are the main soil pest, a combination of resistant tomato or grafted cucumber and avermectin is recommended. When fungal or bacterial diseases are present in addition to nematodes, dazomet and metham sodium are used.

Metham sodium (35-42%) is applied through the drip irrigation system under PE film at a rate of 50-100g/m2. Some farmers apply it as a drench or with flood irrigation water, particularly in plastic tunnels (Carabedian and Gundy, 1983).

Actions for alternative (s) implementation

Complete MB phase-out was supported between 2009 and 2012 by the MLF in Beijing, Shandong and Hebei Provinces and with UNIDO as international implementing agency, in cooperation with Ministries of Environmental Protection and Agriculture.

Crop yields and soil borne pests control

Nematode control with avermectin is as effective as with MB (Table 1). A combination of avermectin with grafting, resistant cultivars or fungicides controls *Fusarium* wilt, damping off, *Phytophthora, Alternaria* and other root rots and nematodes.

Table 1 Crop yields from MB and avermectin in Beijing in 1998-1999

Crop	Yield using MB (t / ha)	Yield using avermectin (t / ha)
Autumn Tomato	116.3	109.6
Spring cucumber	63.0	57.0

Costs and profitability

Avermectin costs are almost 90% lower than those of MB and since yields are similar, avermectin is more profitable for tomato and cucumber. It is also easier to use than MB and does not cause phytotoxicity or plant-back delays, thus it is the preferred option for many tomato and cucumber growers in plastic tunnels. Resistant tomato cultivars and grafted plants (cucumber and tomato) are generally produced directly by the farmers, but some also buy commercial grafted seedlings. The cost is 0.08-0.24 USD/seedling.
Dazomet costs 2,419 USD/ha, metham sodium 973-1,945 USD/ha and plastic film USD 1,354/ha.MB cost is 3,592 USD/ha. Since alternatives are cheaper than MB, farmers accepted the alternatives quickly in cucumber and tomato.

References

Bull Don L, Ivie G Wayne, MacConnell John G, Gruber Virginia F, Ku Chia C, Arison Byron H, Stevenson James M, VandenHeuvel William JA (1984) Fate of avermectin B1a in soil and plants. Journal of Agricultural and Food Chemistry 32. (1):94-102.

Cao Aocheng (1999) The new alternative of methyl bromide--avermectin. In: Research Progress in Plant Protection and Plant Nutrition China Agriculture Press, pp 327-328.

Cao Yuxin (1994) Control of cucumber root knot nematode by using avermectin 1.8EC (in Chinese). Chinese Agricultural Science Bulletin 10:16-18.

Carabedian H., Gundy S.D. (1983) Use of avermectine for the control of Meloidogyne incognite on tomatoes. Journal of Nematology 15 (4):503-510.

Putter I (1981) New insecticides and acaricides and nemaericide-avermectins. Experientia 37:963-964.

Qiao Kang, Liu Xia, Wang Hongyan, Xia Xiaoming, Ji Xiaoxue, Wang Kaiyun (2012) Effect of abamectin on root‐knot nematodes and tomato yield. Pest management science 68. (6):853-857.

Sasser JN, Kirkpatrick TL, Dybas RA (1982) Efficacy of avermectins for root-knot control in tobacco. Plant Disease 66:691-693.

Tomlin CDS (1997) The pesticide manual, 1997. British Crop Protection Council 49.

Prepared by Aocheng Cao, MBTOC member Department of Pesticides, Institute for Plant Protection, Chinese Academy of Agricultural Sciences. Beijing 100193, P. R. China. Phone:+86 10 62815940; Fax:+86 10 62894863 Email: aochengcao@ippcaas.cn

2. *Alternatives for preplant (soils) uses in non-Article 5 Parties*

Case Study 1. Soil biodisinfection and agroecological basis for vegetables in Spain

Initial situation

Spain is the second largest vegetable producer in Europe, and used to be one of the highest consumers of MB, with reported consumption at 5,157 tons in 1998 (Barres *et al*., 2006). Ten years later, Spain managed to reduce and shortly thereafter phase-out its use through different alternatives. Limited access to chemical alternatives, high prices of some non-chemical systems, emergence of virulent soil borne pathogens, and other factors, led to focusing on agro-ecological options, for example organic by-products used for soil biodisinfection which reduce populations of soilborne pathogens, and may be combined with most of the non-chemical alternatives (Bello *et al*., 2008, 2010).

Description of the alternative (s) implemented

A change in the production model was proposed, based on agronomic criteria. Organicmaterials, which emit gases and other compounds with biocidal or biostatic effect that can regulate pest populations during decomposition are used. This is the basis of the concept of soil biodisinfection, which is used within a biological and environmental diversity approach (Barres *et al.,*2006, Bello *et al.,* 2010, López-Pérez *et al.,*2010, Castro Lizazo *et al*., 2011, Díez Rojo *et al*., 2011).

Actions for alternative implementation

Nematodes were chosen as a model for developing soil biodisinfection since this group includes both phytoparasitic and predatory species, which are of interest in the decomposition and assimilation of organic matter in the soil. Biodisinfectants used include solid products such as manures and crop residues, or liquids such as vinasses derived from the alcohol industry, alpechins from the olive industry and slurry from livestock systems. Initial work was aimed at establishing appropriate dosages and duration of the process *in vitro* and in soil under laboratory conditions and later the results were transferred to the field, in protected vegetable crops, ornamentals, strawberries and extensive systems in various productive regions around Spain. Research focused on nematodes of the genus *Meloidogyne*, and established their biogeographical structure, races and biotypes, as a basis for management protocols.,The effects of biodisinfectants on saprophytes, predators and soil bio-indicators were also studied, as well as on soil fertility and crop production are also been taken into account (Bello *et al*.. 2008, 2010; Melero-Vara *et al*..2012; Núñez-Zofío *et al*..2013).

Crop yields, and control of soil borne pests

Soil biodisinfection with organic matter in a C / N ratio of 8:20 was effective, using both solid and liquid products, generating gases. Effectiveness increases when the treatment is combined with solarisation (biosolarisation) ensuring appropriate humidity levels to facilitate organic matter decomposition diffusion of the substances emitted through the soil profilr (Martínez *et al*..2009; Núñez-Zofío *et al.* 2011, 2012). The effect is generally biostatic, so gases must be retained in contact with the soil, where they exert a selective action increasing the number of saprophytic organisms. Soil biodisinfection is more effective when physical, chemical and biological properties of are also considered and can lead to reductions in water and fertilizer consumption.

Costs and profitability

Biodesinfection has been extended to different areas of Spain, and has been found to be economically feasible, with. the main limiting factor being the transportation cost of the biodisinfectants. Using local resources is thus important (Piedra Buena *et al.,*2007;Díez Rojo *et al*.. 2011), as well as the connecton between agriculture and livestock as complementary resources (Bello and González 2012).

Current situation'

Several years after the last CUEs were approved for peppers, cut flowers and strawberries (the last crops using MB for controlled uses in 2010) these sectors have completely and successfully replaced MB. Production systems now rely heavily on agronomic criteria, which are used to manage pests and diseases (Barres *et al.,*2006;Zanón and Jordá 2008;García Ruíz *et al*., 2009; Díez Rojo *et al*., 2011;Bello *et al*., 2011, 2013;González *et al.,*2013a,b; González Ruiz *et al*.,2014).

Selected references

Barres MT, Bello A, Jordá C, Tello JC. 2006. La Eliminación del Bromuro de Metilo en la Protección de Cultivos como Modelo Mundial para la Conservación del Medio Ambiente. MAPA, Madrid, 515 pp.

Bello A, Díez Rojo MA, López Pérez JA. 2013. Biodesinfección de suelos, investigación participativa y desarrollo rural. Cambio climático, destrucción de la capa de ozono. XXI Jornadas Técnicas Estatales SEAE. Desarrollo Rural, Innovación Agroecológica y Agricultura Ecológica en la PAC. Alcalá de Henares, Madrid, 26-27 septiembre, 15 pp.

Bello A, Díez Rojo MA, López Pérez JA, Castro I, Gallego A. 2011. Biodesinfección de Suelos. Sociedad Española de Agricultura Ecológica (SEAE), Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid.(http://vimeo.com/18675250)

Bello A, González JC. 2012. Agroecología y Complementariedad Agraria. 250 pp. http://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2012/libro-agroecologia-bello/libro-agroecologia-bello-sec.pdf

Bello A, Jordá C, Tello JC. 2010.Agroecología y Producción Ecológica**.** CSIC, Catarata, 77 pp.

Bello A, Porter I, Díez Rojo MA, Rodríguez Kabana R. 2008. Soil biodisinfection for the management of soil-borne pathogens and weeds. 3rd Int. Biofumigation Symposium, 21 – 25 Jul., CSIRO Discovery Centre, Canberra, 35 p.

Castro Lizazo I, Díez Rojo MA, López Pérez JA, Díaz Viruliche L, Bello A. 2011. Biodesinfección de Suelos en Producción Ecológica.Dossier SEAE. Valencia. 56 pp. http://www.agroecologia.net/recursos/publicaciones/dossiers/dossier-biodesinfeccion.pdf

Díez Rojo MA, López-Pérez JA, Urbano Terrón P, Bello Pérez A. 2011. Biodesinfección de Suelos y Manejo Agronómico. Ministerio de Medio Ambiente, Medio Rural y Marino, Madrid, Spain, 414 pp. (http://www.magrama.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/libro_de_biodesinfección_tcm7-156245.pdf)

García Ruíz A, Tello JC, Avilés Guerrero M, Ordovás Ascaso J. 2009. Fusariosis del Clavel. Fusarium oxysporum f.sp. dianthi. Últimos Avances en su Control. Edit. Agrotécnicas, 275 pp.

González JC, González Ruiz J, Domínguez M, Afonso R, Domínguez E, Domínguez K, Hernández M, López Cepero J, Piedra Buena A, López Pérez JA, Arias Mª, Tello JC, Bello A. 2013a. Diversidad y complementaridad en la gestión agroecológica. *XXI Jornadas Técnicas Estatales SEAE: Desarrollo Rural, Innovación Agroecológica y Agricultura Ecológica en la PAC.* Alcalá de Henares, Madrid, 26-27 septiembre, 39 pp. https://docs.google.com/file/d/0B-jLDCjL-kpxWFQ5NDVuNzRmbDg/edit.

González JC, González Ruiz J, Domínguez M, Alfonso R, Domínguez E, Domínguez K, Hernández M, López Cepero J, Piedra Buena A, López Pérez JA, Arias Mª, Tello JC, Bello A. 2013b. Diversidad y complementaridad en la gestión agroecológica. Investigación participativa y desarrollo rural. Ae 14, 48-49.

González Ruiz J, Domínguez M, Afonso R, Domínguez E, Domínguez K, Hernández M, González JC, Ballester J, Gallego A, López Cepero J, Piedra Buena A, López Pérez JA, Torres Nieto JM, García Ruiz A, Arias M, Lacasa A, Tello JC, Gonzálvez V, Bello A. 2014. Agricultura familiar, investigación agroecológica participativa y formación. *Simposium Agricultura Familiar Agroecológica*, SEAE. Lugo, 18 - 20 junio, 15 pp.

López Pérez JA, Roubtsova T, García M de Cara, Ploeg A. 2010. The potential of five winter-grown crops to reduce root-knot nematode damage and increase yield of tomato. *J. Nematol.* 42, 120-127.

Martínez MA, Martínez MC, Bielza P, Tello J, Lacasa A. 2009. Effect of biofumigation with manure amendments and repeated biosolarisation on *Fusarium* densities in pepper crops. *J. Ind. Microbiol. Biot.*38, 3-11.

Melero-Vara JM, Lopez-Herrera CJ, Basallote-Ureba MJ, Prados AM, Vela MD, Macias, FJ, Flor-Peregrin E, Talavera M. 2012. Use of poultry manure combined with soil solarisation as a control method for *Meloidogyne incognita* in carnation. *Plant Dis.* 96, 990-996.

Nuñez-Zofio M, Larregla S, Garbisu C. 2011. Application of organic amendments followed by soil plastic mulching reduces the incidence of Phytophthoracapsici in pepper crops under temperate climate. Crop Prot. 30, 1563-1572.

Nuñez-Zofio M, Larregla S, Garbisu C. 2012. Repeated biodisinfection controls the incidence of Phytophthora root and crown rot of pepper while improving soil quality. Spanish J. Agricultural Research 10, 794-805.

Nuñez-Zofio M, Larregla S, Garbisu C, Guerrero MM, Lacasa CM, Lacasa A. 2013. Application of sugar beet vinasse followed by solarisation reduces the incidence of Meloidogyne incognita in pepper crops while improving soil quality.Phytoparasitica 41, 181-191.

Piedra Buena A, García-Alvarez A, Díez-Rojo MA, Ros C, Fernández P, Lacasa A, Bello A. 2007. Use of pepper crop residues for the control of root-knot nematodes. BioresourTechnol. 98, 2846-2851.

Zanón MJ, Jordá C. 2008. Eradication of Clavibacter michiganensis subsp. michiganensis by incorporating fresh crop debris into soil: preeliminary evaluations under controlled conditions. Crop Prot. 27, 1511-1518.

Provided by Jose Antonio López-Pérez, Miguel A. Díez-Rojo, J.M. Torres and Antonio Bello. Centro Agrario Marchamalo (JCCM)

Case Study 2. Alternatives to methyl bromide for strawberry runner production in Japan

Initial situation

The most important strawberry soilborne diseases in Japan are fusarium wilt (*Fusarium oxysporum,* f. sp. *fragariae*), anthracnose (*Collectotrichum gloeosporioides*), root lesion nematode (*Pratylenchus vulnus*) and root knot nematode (*Meloidogyne hapla*). Since all current varieties are susceptible to these pathogens, pest-free certification for strawberry runners is not required. Growers obtain virus-free mother plant seedlings from the growers associations and use them for runner production.

Actions for replacing MB

Japan has phasedout controlled uses of MB entirely, including strawberry runners production. Agricultural research and plant protection technology extension centers were encouraged to develop chemical and non-chemical alternatives, and pesticide industries were urged to cooperate in this effort. Currently, available alternative technologies have been widely adopted by growers in many strawberry runner production regions.

Description of the implemented alternatives

Mother stock is grown in pots, in soil or substrate . Soil is treated with chloropicrin (liquid, tape or capsule) or dazomet (granules). Substrates (peat moss, coconut hull, bark manure, saw dust, vermiculite, rice hull, sand etc.) are used only for mother stock and nursery stock production, and are bought from specialized companies providing clean materials.

Non-chemical alternatives, including solarisation and anaerobic soil disinfestation are available for strawberry fruit field production (Ueno *et al.*. 2006; Yamada *et al.,* 2003; Yonemoto *et al.,* 2006). Available chemical treatments include Pic, dazomet, 1,3-D/Pic, and a mixture of MITC and 1,3-D.

Current situation

Strawberry stock production takes place in protected houses to help decrease incidence and severity of *Collectortichum gloeosporioides* which is encouraged by free water (rain). Two types of production systems are used: A raised rack type setup, where plant plugs are placed, and ground beds, directly in the field. Racks have become increasingly popular.

References

Department of Agriculture and Forestry of Nagasaki Prefecture (2009) Establishment of standard technology on strawberry production. Nagasaki Standard Technology of Agriculture and Forestry.

Shinozaki Tsuyoshi, Matsuzaki Yukihiro and Yasunaga Tadamiti (2003). Control of Fusarium Wilt by Methyl Bromide Substitution in Strawberry. *Annual Report of Ehime Agricultural Research Institute* 37,27-34

Ueno Kiyoshi, Kaneko Katsuhiro, Taniguchi Enosuke and Nagasawa Sayuri (2006). Control of Fusarium Wilt and Nematode on Strawberry by Soil Reduction in Yamagata Prefecture. *Ann. Rept. Plant Prot. North Japan* 57:62-64

Yamada, K., *et al*. (2003). Control of Fusarium wilt on strawberry by Soil Reduction. *Annual Report of the Kanto-Tosan Plant Protection Society* 50, 49-52

Yonemoto Kengo, Hirota Keisuke, Mizuguchi Shoko and Sakaguchi Kenji (2006). Utlilization of the sterilization by soil reduction in an open air field and its efficacy against Fusarium wilt of strawberry. *Proc. Assoc. Pl. Protec. Shikoku.* No 41:15-24

Provided by Akio Teteya (akio.tateya@nifty.com), Tokyo Japan, member of MBTOC

3. Alternatives to MB use for QPS purposes

Case Study: Minimum use of methyl bromide for quarantine treatment in Japan

This case study describes the measures that Japan has implemented to reduce the amount of MB for the treatment of imported goods in response to Decision VI/11(c) and XX/6 urging Parties to minimize the use and emissions of methyl bromide (MB) for QPS (Table 1, Anonymous 2014). Such measures include updating Japan's non-quarantine pest list, and improved pest identification on entry. Further, all fumigation chambers now require official control and approval by MAFF to ensure a high gas retention capability and appropriate air tightness and correct labeling of MB cylinders. No repeat MB treatments are allowed, and dosage rates for grain have been optimized to ensure fumigation effectiveness (Table 2, Anonymous 2011). Heat treatment of wood packaging for ISPM 15 is now required, to minimize MB use and emissions.

Import plant inspection

When plant products arrive at the Japanese point of entry, the consignee submits the import plant inspection application form No. 4 to the plant quarantine inspector (PQI) who then inspects the consignment. If quarantine pests are intercepted, the respective pest names are entered into the form by the PQI and the consignee is required to follow phytosanitary measures for custom clearance.

Phytosanitary treatment

The pest control operator (PCO), hired by the consignee, submits the phytosanitary treatment plan for the approval of a PQI, and the consignment is loaded into the fumigation chamber (which in turn needs approval from Japan's MAFF). Treatment efefctiveness is checked by the PQI on the basis of survival of the test insects and/or the level of the remaining gas concentration. When the fumigation treatment is considered successful the PQI clears the consignment.

Efforts to minimise use and emission of methyl bromide

MB fumigation as a phytosanitary treatment must strictly and exclusively be applied for those consignments in which quarantine pest insects had been found.

Updating the list of non-quarantine pests

Non-quarantine pests of 334 species have been listed (Anonymous 2014) as of February 24th 2014 by pest risk analysis (PRA) based on ISPM-2. In the future, as progress with PRA is made, the number of non-quarantine pests will most probably increase. Many species of grain pests are now included in this list and as a result MB use has been significantly reduced. In recent years the number of plant commodities in which quarantine pests are found has decreased. Further, the volume of log imports that is subject to quarantine inspection and frequent treatment with MB, has significantly decreased.

Improving pest identification skills of plant quarantine inspectors

PQIs have attended training sessions on pest identification, whether these are classified asquarantine or non-quarantine pests and if treatment of the consignment is or not required. Unnecessary MB use against non-quarantine pests is thus avoided.

Registration of methyl bromide for exclusive quarantine use

MB was registered in December 24th 1994 for exclusive use as a quarantine treatment, independent of the generally regulated use. Therefore, MB for quarantine treatment is not allowed for soil or post harvest treatment. It is been clearly identified with a red label on the cylinder for easy recognition. The PCO engaged in quarantine treatment is strictly instructed to use MB exclusively for quarantine pests no other circumstances.

Optimization of dose rates in grain fumigation schedule

MB dose rates are prescribed in the fumigation schedule to ensure complete disinfestation under various fumigation conditions as shown in table 2 (Anonymous 2011), whilst ensuring minimum use and emissions. They are respectively set under consideration of various fumigation factors:

(1) *Gas retention capability and air tightness of the fumigation chamber*, which should be optimum. Fumigation chambers for quarantine use are designated by Japan MAFF as category class super A, class A, class B and class C according to the quality of these parameters. The higher the gas retention capability of the chamber, the lower the dose applied.
(2) *Fumigation duration*: Dose rates vary depending on whether the fumigation lasts 24 h, 48 h or 72 h. The longer the fumigation, the smaller dose rate is applied. A 48 h fumigation period is presently preferred in view of reduced fumigation costs.
(3) *Grain loading of bagged grain in a warehouse or bulk grain in a silo*: The fumigant penetrates and spreads easier throughout the grain when it is treated in bags rather than in bulk. The dose rate for grain in bags is thus lower than for bulk grain in silos.
(4) *Plant products with gas absorption*: The dose rate is set in consideration of the level of MB absorption by plant products, being lower for products with lower absorption. For example, dose rates for soybeans are higher than for wheat because the former tend to absorb more MB due to their higher protein content. Dose rates for wheat flour are higher than for wheat grain because flour absorbs more MB than grain.
(5) *Grain temperature*: Pests are more sensitive to MB at higher temperatures. Dose rates are thus set depending on the grain temperature - whether < 10°C, between 10°C-20°C or > 20°C.
(6) *Loading rate of the consignment in the chamber*: The loading rate (LR) is expressed in terms of tonnes/m^3. High volumes of grain absorb more MB so a higher dose rate is necessary for effective insect disinfestation. Dose rates may thus vary between LR<0.3

t/m^3, LR 0.3 - 0.5 t/m^3 and LR>0.5 t/m^3 for flat fumigation chambers and between LR<0.3 t/m3 and LR>0.3 t/m3 for silos. The LR is not differentiated for different types of chambers (silo of concrete, stainless steel bin or warehouse fumigation).

(7) *Circulation system in the fumigation facility*: Lower dose rates can be used if appropriate air circulation systems are used within the chamber, ensuring easier and more uniform fumigant distribution. Currently, circulation systems are installed in the majority of fumigation chambers in Japan.

Categorisation of fumigation chamber for quarantine use

Fumigation chambers for plant quarantine treatment are categorised by Japan MAFF according to their gas retention capability. Accordingly, they are ranked as class Super A, class A, class B or class C. The gas retention capability is determined by gas concentration remaining inside the empty chambers 48 hours after MB application. If this is higher than 85% of the initial dose rate, the chamber is categorized as class Super A; if over 70%, the chamber is categorized as class A; a chamber with a concentration above 55% is categorized as class B and over 40% as class C. Chambers with a gas concentration below 40% are not allowed for quarantine fumigation treatments. Chamber owners are required to improve the gas tightness to category super A or class A and currently, 99.8 % of the chambers comply with this rule. No Class C chambers are used for phytosanitary fumigation treatment (Table 3, Anonymous 2014).

Determination of air tightness of fumigation chamber

PQI conducts air tightness tests to determine whether a chamber is fit for quarantine treatments. This is done at the owner's expense.

In the case of a warehouse, air is introduced into an empty premise until an air pressure of 55 mm Aq is reached. The warehouse is then sealed and left to sit until the pressure goes down to 50 mm Aq. If the time necessary for a further pressure drop from 50 mm Aq. to to 45 mm Aq. is longer than five minutes, the chamber is categorized as class Super A. If that time is between 5 and 45 mm Aq., the warehouse is classified as class A.
For silos, the air pressure is raised up to 550 mm Aq. by introducing air into the empty silo. Once sealed, the pressure decline is observed until it reaches 500 mm Aq. If after 20 minutes the pressure remains above 400 mm Aq., the silo is lassified as class Super A; if the pressure difference is between 200 and 400 mm Aq., then it is classified as class A.

Other measures for minimizing MB use and emissions

Various additional measures have been taken to minimize the use and emission of MB when it is applied for quarantine purposes as follows:

(1) *Efforts to avoid fumigation failure*: If according to PQI a fumigation treatment with MB has failed (ie by the presence of surviving pests or the gas concentration remaining after treatment), it will not be repeated. Rather, aluminum phosphide or carbon dioxide which take a longer time and are more costly are indicated. The PCOs must follow this instruction or custom clearance is denied and re-shipment to another country or destruction of the consignment is the only option.
(2) *Encourage the use of fumigation chambers in accordance to the size of the commodity consignment*: The MB application dose is set in accordance with the size of the fumigation chamber, not the volume of the consignment.
(3) *No mixed loading of commodities with different absorption rates*: If plant products with different MB absorption rates are loaded together, the dose rate is set according to the plant category with higher absorption rate no matter how small the proportion of product

with higher absorption rate is. To avoid this partial overdosing, it is strongly recommended to fumigate mixed consignments in separate chambers.

(4) *Encourage use of heat treatment for wood packing materials instead of MB*: Plant protection authorities suggest applying heat treatment to wood packing materials taking into account the most recent version of ISPM 15 (IPPC, 2013, Sela et al., 2014). Methyl bromide fumigation is only carried out when the consignment is already packed. Therefore, in Japan heat treatment is used for the majority of disinfestations of wood packing material and methyl bromide fumigation rarely used.

Table 1. Consumption of MB for Quarantine treatments (ref 1)

	Year						
	2007	2008	2009	2010	2011	2012	2013
Amount (t)	867	706	542	511	547	499	503

Table 2. Extract of methyl bromide dose rates in fumigation schedules (ref 2)

Fumigation facility	**Commodity**	**Loading rate (LR) of the commodity in the chamber with forced air circulation tonnes/m3**	**MB dose rate (g/m³) for 48 h treatment at >20°C for the respective category of designated gas retention capability of the fumigation chamber**			
			Super A	**A**	**B**	**C**
Warehouse	Bagged rice, wheat and coffee bean	0.3> LR 0.3≦LR <0.5 LR□0.5	8 10 12	9 11 13	10 13 15	12 15 18
	Bagged maize and millet	0.3> LR 0.3≦LR <0.5 LR□0.5	10 12 15	11 13 17	13 15 21	15 18 24
	Bagged soybean, kidney bean, pea nuts	0.3< LR 0.3≦LR <0.5 LR□0.5	12 13 19	13 15 21	15 18 26	18 21 30
Silo	Bulk rice and wheat	0.3< LR 0.3□LR	11 16	12 18	14 21	17 25
	Bulk maize and millet	0.3< LR 0.3□LR	14 22	15 24	17 28	21 34
	Bulk soybean, kidney bean, peanuts	0.3< LR 0.3□LR	15 23	17 25	20 29	24 35

Dimension of LR: Ratio between the volume of the consignment (tons) and the chamber volume (m³)

Table 3. Numbers of designated fumigation chambers for quarantine treatment as of August 1st 2014 (ref 4)

Location of the treatment	Number of chambers in each gas tightness classification				Total
	Super A	A	B	C	
Warehouses	587	661	19	0	1,267
Silos	2,622	7,060	5	0	9,687
Total	3,209	7,721	15	0	10,945
Number of chambers in % of the total number	29.3	70.5	0.2	0	100
Size of chamber space (m^3) in percent of the total	38.9	60.8	0.3	0	100

References

Anonymous 2014. Delivery amount of methyl bromide and major alternatives. Japan Fumigation Technology Association. Nikkunkyo Dayori of the volume of March 31st 2014. No.115, page 6.

Anonymous 2011. Methyl bromide dose rate in quarantine treatment. The Quarantine Guideline for Grain Import. Attached table. No. 2628, February 6th, 1971. Latest revised version as of September 7th. 2011. Ministry of Agriculture, Forestry, and Fisheries. http://www.pps.go.jp/law_active/Notification/basis/8/53/html/53.html

Anonymous. 2014. List of non-quarantine pest insect and disease. Ministry of Agriculture, Forestry and Fisheries Announcement, No. 296, February 24th 2014, page 13-16 and 28. Ministry of Agriculture, Forestry and Fisheries. http://www.pps.go.jp/law_active/Notification/basis/5/245/html/245.html

Anonymous 2014. Statistics on fumigation chambers for the use of quarantine treatment designated by Plant Protection Stations MAFF. Text on safe use of fumigants for quarantine treatment. Edited by Japan Fumigation Technology Association 2014, page 25.

FAO 2013. Revision of International Standards for Phytosanitary Measures No. 15. Regulation of wood packing material in international trade. Annex 1. Page ISPM 15-14.

Sela, S., Schröder, T., Mamoru M. and Ormsby, M. 2014. Explanatory document for ISPM 15:2009 (Regulation of wood packaging material in international trade), International Plant Protection Convention (IPPC), online: https://www.ippc.int/sites/default/files/documents/20140430/ispm_15_ed_withannexes_2014-04-30_201404300908--1.44%20MB.pdf, 45 pp

Provided by Akio Tateya (akio.tateya@nifty.com), Tokyo Japan, MBTOC member

Annex 2

Annex 2. Methyl Bromide Technical Options Committee - Committee Structure

MBTOC structure as at 31 December 2014

Co chairs

Mohamed Besri	Institut Agronomique et Vétérinaire Hassan II Morocco
Ian Porter	La Trobe University Australia
Marta Pizano	Consultant Colombia

Subcommittee chairs, chapter lead authors for this Assessment

Chapter 1 - Executive summary
Chapter 2 - Introduction to the assessment - lead author, *Marta Pizano.*
Chapter 3 - Methyl Bromide production and consumption (controlled uses) **-** lead authors, *Marta Pizano, Alejandro Valeiro, Eduardo Willink.*
Chapter 4 -Alternatives to Methyl Bromide for soil treatment –*Mohamed Besri, Ian Porter*.
Chapter 5 - Alternatives for Treatment of Post-Harvest Commodities and Structures – *Christoph Reichmuth.*
Chapter 6 – Quarantine and Pre-shipment **-** *Marta Pizano, Cristoph Reichmuth*
Chapter 7 – Progress in Methyl Bromide phase-out. Lead authors, *Marta Pizano*.
Chapter 8 - Economic Issues Related to Methyl Bromide Phaseout. Lead author *Nick Vink*
Chapter 9 - Methyl Bromide emissions. Lead authors *Ian Porter, Jonathan Banks*

Committee contact details and Disclosure of Interest
To assure public confidence in the objectivity and competence of TEAP, TOC, and TSB members who guide the Montreal Protocol, Parties to the Protocol have asked that each member to disclose proprietary, financial, and other interests. Disclosures of Interest (DOI) are posted at the Ozone Secretariat website and are updated as necessary, once a year at minimum. They can be accessed at
http://ozone.unep.org/en/disclosure_of_interest.php?body_id=6&committee_id=6

Table A-1 below contains the lists of MBTOC members at December 31st, 2014. As indicated in Chapter 2, as of 1st January 2015, MBTOC membership has been reduced to twenty members.

TABLE A-1.MBTOC MEMBERS AS AT DECEMBER, 2014

Chairs		Affiliation	Time of service	Country
1. Prof. Mohamed Besri	M	Department of Plant Pathology, Institut Agronomique et Vétérinaire Hassan II	A	Morocco, A5
2. Ms. Marta Pizano	F	Consultant, Hortitecnia Ltda.	A	Colombia, A5
3. Dr. Ian Porter	M	La Trobe University	A	Australia, Non-A5
Members		**Affiliation**	**Time of service**	**Country**
4. Dr. Cao Aocheng	M	Institute for Plant Protection, Chinese Academy for Agricultural Sciences	A	China, A 5
5. Dr. Jonathan Banks	M	Consultant	A	Australia Non-A5
6. Dr. Chris Bell*	M	Consultant, retired from Central Science Laboratory (Government research)	A	UK Non-A5
7. Mr. Fred Bergwerff	M	Eco2, Netherlands	B	Netherlands Non-A5
8. Dr. Peter Caulkins*	M	Associate Director, Special Review & Reregistration Division US EPA	B	USA, non-A 5
9. Mr. Ricardo Deang*	M	Consultant	A	Philippines A5
10. Dr. Raquel Ghini	F	EMBRAPA Meio Ambiente – Jaguariúna Sao Paulo	B	Brasil, A5
11. Mr. Ken Glassey	M	Senior Advisor Operational Standards Biosecurity New Zealand, Ministry of Agriculture and Forestry Wellington	B	New Zealand Non- A5
12. Mr. Alfredo Gonzalez	M	Fumigator	A	Philippines A5
13. Ms. Michelle Marcotte*	F	Consultant	A	Canada Non-A5
14. Mr. Takashi Misumi	M	Quarantine Disinfestation Technology Section, Ministry of Agriculture, Forestry and Fisheries MAFF	B	Japan Non A5
15. Dr. David Okioga*	M	Kenya Ozone Office. Min. of Environment	A	Kenya A5
16. Prof. Christoph Reichmuth	M	In transition to Professor at Humboldt University Berlin. Retired from JKI Germany (Government research) (October 2010)	B	Germany Non-A5
17. Mr. Jordi Riudavets	M	IRTA-Department of Plant Protection. (Government Research)	B	Spain Non-A5
18. Mr. John Sansone*	M	SCC Products (Fumigator)	A	US Non-A5
19. Dr. Sally Schneider*	F	National Program Leader – Horticulture, Pathogens & Germplasm, USDA	A	USA, non=A5
20. Dr. JL Staphorst	M	Consultant, Plant Protection Research Institute (PPRI), Agriculture Research Council (ARC)	A	South Africa, -A5
21. Mr. Akio Tateya	M	Technical Adviser, Syngenta Japan	A	Japan, non-A5
22. Mr. Robert Taylor*	M	Consultant, retired from UK research institute	A	UK Non-A5
23. Mr. Chris Watson*	M	Consultant, retired from IGROX Ltd (Fumigator)	A	UK Non-A5
24. Mr. Jim Wells*	M	Environmental Solutions Group, LLC, Sacramento, CA	A	USA, non-A5
25. Mr. Alejandro Valeiro	M	National Project Coordinator, National Institute for Agriculture and Technology,Tucumán	A	Argentina, A 5
26. Dr. Ken Vick	M	Consultant, USDA	A	United States

				Non-A5
27. Prof. Nick Vink	M	University of Stellenbosch, Department of Agricultural Economics	A	South Africa, A 5
28. Mr. Eduardo Willink	M	Estación Experimental Agroindustrial Obispo Colombrés, Tucumán	A	Argentina A5
29. Dr. Suat Yilmaz	M	West Mediterranean Agricultural Research Institute – BATEM, Antalya	B	Turkey, A 5
TOTALS			A= more than 10 yrs; B= 5-10 yrs; C= 0-5 yrs	F= 4 M = 25 A5= 12 non A5 = 17

* Retired from MBTOC on 31 December 2014.