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Breaking the bondage to methyl bromide in agriculture – UNIDO experience

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Abstract

Key words: Ozone depleting substances, grafting, compost, biofumigation, soilless production, biocontrol, sustainable production.

For decades, methyl bromide was used as the fumigant of choice to rid the soil of noxious pests, diseases and weeds in the pre-plant stage, particularly in intensive agriculture around the world. Breaking the chains of the methyl bromide bondage by 2015 in developing countries - as set by the Montreal Protocol on the Substances Depleting Ozone Layer – has been a great challenge, but at the same has created an opportunity to promote a variety of non-chemical alternatives. By initiating the transition towards sustainable technologies, United Nations Industrial Development Organization (UNIDO) – as one of the implementing agencies of the Protocol - has been instrumental in phasing-out methyl bromide in developing countries. In partnership with local governments and institutions, UNIDO has brought the benefits of environmentally friendly alternatives to growers in various sectors around the world. Through the successful adoption of novel technologies such as vegetable grafting in Mexico, bio-control agents in Honduras, soilless systems in Turkey, biofumigation + solarization in Ecuadorean flowers or compost technology in Morocco, these growers have developed successful disease and pest management programs that not only are not reliant on methyl bromide or other soil fumigants, and which are proving to be equally efficient and sustainable in the long term. Such programs are further giving market headway to various agricultural sectors by making them more competitive in international markets, which are increasingly requiring products grown within environment-friendly standards.

INTRODUCTION

Due to its high ozone-depleting potential (0.6), methyl bromide (MB) was declared an Ozone Depleting Substance (ODS) in 1992 under the Copenhagen amendment of the Montreal Protocol. Different reduction and phase-out schedules were agreed for developed and developing countries, and a special fund was created to assist developing nations with the phase-out, set for 1st January 2015. Four implementing UN agencies were appointed to undertake this task; among these, UNIDO has played a prominent role, coordinating numerous projects to demonstrate and later adopt alternatives to MB in developing countries. Phase-out is now well

advanced, with over 80% of the MB tonnage once consumed already replaced (TEAP, 2013).

This achievement, however, has met with many difficult challenges. For many decades, MB was used as a fumigant, mainly as a pre-plant treatment to rid the soil of pests, diseases and weeds that, if left unchecked, can cause severe losses to high-value crops like strawberries, tomatoes, flowers, peppers and melons (MBTOC, 2011; Pizano et al., 2010). Although technically feasible alternatives to MB have been identified for virtually all previous uses of this fumigant (MBTOC, 2011), their adoption has often required changes in cropping practices sometimes including infrastructure, different logistics, and often a change in attitude towards crop production and pest control on the part of farmers. It has become clear that a combination of practices and/or alternatives provides the best long-term strategy for growers as wide spectrum fumigants and other chemicals are being subjected to regulatory constraints. Together with increasingly stringent quality requirements imposed by developed countries importing the crops in question, this has not been an easy feat.

In many instances, alternative technologies have originated in industrialised countries, but their successful adoption in developing countries has required adaptation to their particular circumstances to ensure not only technical, but also economic and commercial feasibility. Training and technical assistance have played a major role in this process, as well as ensuring that all key stakeholders of a given productive sector are involved. This paper presents four case studies to illustrate how MB was efficiently substituted in different sectors and regions with non-chemical, efficient alternatives, which are providing a sustainable solution to soil pest management.

CASE STUDIES

Grafting in Mexico

Mexico is the second world exporter of fresh tomatoes, with exports valued at \$1700 million USD in 2012 and a world market share of 21%. It also comes in second in worldwide melon and watermelon exports, valued at \$437 million USD in the same year, representing 18% of the world market (ITC, 2013). Successful expansion of these sectors took place over the last 25 years, with the associated increase in MB use as a soil fumigant, to control pathogens and nematodes causing severe yield and quality losses (Huitrón et al., 2010; Ricárdez et al., 2010). In the period between 1995 and 1998, Mexico became the largest MB user in the developing world, with an average consumption of 1885t (UNEP, 2013). In 2007, MB consumption was concentrated in six main sectors: tomato, cucurbits, peppers, strawberries, flowers and structures. Tomato consumption was estimated at 436t and at 312t in cucurbits (melons and watermelons). By 2012 however, consumption had been reduced by over 50% in tomatoes (203t) and had been completely phased-out in cucurbits (SEMARNAT, 2013).

Such significant substitution has been possible in these two sectors mainly through grafting. Through UNIDO projects, grafting units were set up at commercial locations and trials were conducted to identify the best-suited rootstocks and cultivars for both melons and watermelons. These were intended for production in fields infested with *Fusarium oxysporum* f. sp. *melonis*, *Oplidium bornovanus*, and Melon Necrotic Spot Virus (MNSV) in Colima, Mexico, which were previously controlled with MB (Camacho et al., 2011; Huitrón et al., 2009; Ricárdez et al., 2010).

Grafted watermelons grown on non-fumigated soil produced yields that were

between 58 and 115% greater than those of non-grafted plants grown in soil fumigated with MB; plants produced significantly more, and fruit size and firmness were enhanced. In addition, it was possible to reduce planting densities by up to 50% with respect non-grafted plants (Huitrón et al., 2009). In the case of melons, average fruit weight and total yields were significantly higher in grafted plants grown in non-fumigated, infested soils; planting density could be reduced by 60% (Ricárdez et al., 2010) hereby reducing production costs significantly.

In the case of tomatoes, grafted plants are allowing Mexican growers to obtain high yields, and not face losses caused by *F.o. f.sp. radices-lycopersici* which previously reached levels as high as 45% (Francisco-Illescas and Camacho-Ferré, 2009). Through the UNIDO project, grafting facilities have been established at various commercial sites and rootstocks that are best suited for the preferred varieties produced in Mexico have been selected. An active training and dissemination program involving hundreds of growers and other stakeholders has further supported commercial uptake of this technology (García and Ferré, 2011). Final phase-out of MB in the tomato sector is expected in 2014.

Bio-controls in Honduras

Cucurbits are a highly important export commodity and source of revenue and employment for Honduras. Exports have shown a steady increase over recent years, passing from \$27 million USD in 2002, to \$35 million in 2008. In 2012, melon exports were valued at \$59 million USD and watermelons at \$7.4 million (ITC, 2013). The largest importer is by far the United States, but exports to the EU have increased in the last five years and now represent about 15% of the share (ITC, 2013).

The cucurbit sector has traditionally accounted for over 90% of the MB consumption in that country (UNIDO, 2005), where it was used to control soilborne fungi such as *Fusarium oxysporum* f. sp. *melonis* and *Monosporascus cannonballus* and nematodes (*Meloydogyne* spp.) A project was implemented by UNIDO, which will phase-out 432.4t of MB by 2014. Initially, trials were aimed at adapting the grafting technique to Honduran conditions, which proved easier for watermelons. Some incompatibility between rootstocks and scions were found in melons and the fertigation regime had to be modified. Grafting units were set up with funding provided by the project, and a strong training component was included. It was soon determined that grafting would work best if included into an integrated cropping system, and a strong biocontrol component was included, which proved very successful.

Interest towards biological control was spurred by increased options to export Honduran melons to the EU, in particular the Netherlands, the UK and Belgium, all of which indicated strong preference (and willingness to pay a higher price) for melons grown without toxic chemicals (UNIDO, 2005). Biological control mainly consists of massive applications of two different strains of *Trichoderma harzianum*, and one strain of *Bacillus subtilis* isolated from the Choluteca region where most of the melon production occurs (Michel, 2009; Martínez et al., 2010). Biocontrol agents are reared and multiplied directly at the farms, in simple yet high quality labs installed for that purpose. Growers use this system both with grafted and non-grafted plants (Arias, 2013).

Trials were conducted through the project jointly between growers and researchers, in first instance to search and select local strains of *Trichoderma* that might offer the best pathogen control (Martínez et al., 2010). Ten isolates from different zones were obtained and were tested against *F. oxysporum* and *M.*

cannonballus; the best performing isolates were then tested in infested plots, and finally, two strains of *T. harzianum* were selected for field trials. One of these strains proved significantly better as a biocontrol agent for *F. oxysporum* through substrate competition and mycoparasitism, whilst both proved to be efficient parasites of *Monosporascus*. This biocontrol option has been adopted successfully by Agrolibano, one of the largest melon exporters participating in the project (Martínez et al., 2010).

To ensure successful adoption at the commercial level, the project additionally provided laboratory facilities to multiply the biocontrol agents. A brief representation of one such units presently operating in Excotur (also a large melon exporter) appears in Fig.1. In summary, each lab contains three units: a very clean, enclosed area labelled “in vitro” where strains are introduced and maintained; a clean, enclosed area where massive multiplication takes place where the growing substrate is prepared and then inoculated, dried and formulated; and a clean and open area where pathogen diagnosis is conducted and beneficial microorganism populations are monitored. *Trichoderma* may be propagated on a substrate of rice hulls, bran and flour with calcium nitrate (2.8×10^{12}), or in a liquid suspension of water, sugar, molasses and calcium nitrate (1.8×10^9). *B. subtilis* is also propagated on rice (3.2×10^{12}) or a liquid suspension of sugar and sterile molasses ($2.9 - 3.1 \times 10^{10}$ or 10^{11}). Biocontrols are incorporated into the soil at the pre-plant stage and throughout the cropping cycle (10-12 applications per cycle) at a rate of 30-38kg/0.7 ha (1mz) of *Trichoderma* per cycle and 100 – 120 L/ 0.7 ha (1mz) of *Bacillus subtilis* in suspension of melon cropping area (A. Reyes, pers commun., 2013).

Successful adoption of this system is now widespread with the large melon growers of Honduras, which accounted for a large proportion of the MB used in the past (Arias, 2013). It has further served for valuable information exchange with other melon growers in the region, for example Costa Rica and Guatemala.

Biofumigation + solarisation in Ecuador

Ecuador is the world's third largest flower exporter, with exports valued at USD \$719 million in 2012. MB was traditionally used in the production of cut flowers such as carnations and particularly for “summer flowers”, a category including flower species generally used in bouquets and flower arrangements such as *Gypsophyla paniculata*, *Hypericum*, *Lisianthus*, *Liatris* and others, frequently attacked by fungi like *F.oxysporum* and nematodes (i.e. *Meloidogyne* spp., *Pratylenchus* spp.). A technical assistance project is still ongoing in this sector, aimed at trialling and demonstrating different alternatives of interest to growers, under the coordination of UNIDO. Particular interest has been shown for biosolarization (biofumigation or biodesinfestation coupled with solarisation) a technique giving very good results for example in Spain (Díez-Rojo et al., 2010).

Soil biodesinfestation is based on the emission of volatile and nitrogenous compounds occurring during the decomposition of organic matter, together with other chemical and biological, which contribute to the control of soilborne plant pathogens. When green organic matter is incorporated, an anaerobic phase occurs, which further contributes to pathogen control (Díez-Rojo et al., 2010.) This technique is used commercially in many countries and is most efficient when combined with other options, within an integrated crop management approach (MBTOC, 2011). For example, the combination of biofumigation and solarisation (biosolarisation) has been found to have a synergistic effect by improving the efficacy of both procedures and thereby reducing the time required for solarization and the amounts of organic matter needed for biofumigation (Díez-Rojo, 2010; MBTOC, 2011).

Experiences with Ecuadorean growers are so far very encouraging. Trials have been conducted over the past year, comparing biosolarization with chemical options, particularly 1,3-Dichloropropene + chloropicrin (Agrocelhone®). Trials incorporating different volumes of green plant material + chicken manure into the soil and then covered with clear plastic for a period of 4 weeks were conducted at different locations and with three flower crops: *Gypsophyla*, *Hypericum* and *Lisianthus*. Initial results show, for example, that *Gypsophyla* grown on soil amended with 7kg/m² of plant refuse (from the production areas) + 3kg/m² of chicken manure and then covered with clear plastic for four weeks (during which solarisation occurs) yielded flower stems in the same quantity and weight as soils treated with 1,3-D/Pic; the number of dead plants at the end of the cropping cycle was not significantly different between this treatment and Agrocelhone® (Jácome, 2013). Biosolarization is further providing growers with an improved understanding of soil health management in general. Depleted organic matter, often coupled with deficient fertilization and irrigation practices, appear to be a common cause of sub-optimal plant development and yield decline over time (i.e. “soil fatigue”), and not high incidence of soilborne diseases. The need for MB fumigation was thus questionable in these cases (J. Tello, pers. commun., 2013).

Soil-less culture in Turkey and Morocco

Soilless culture is widely used around the world for the production of crops such as tomatoes, peppers, strawberries, cut flowers, melons, cucurbits and different types of nursery plants, and can be considered an efficient alternative to MB. Although initial investment is often high, increased yields and quality usually compensate for this cost increase (MBTOC, 2007, 2011; Pizano et al., 2010).

Soil-less culture was trialled in Turkey as one of the plausible alternatives to MB for the horticulture sector, through the project implemented by UNIDO, which was aimed at replacing 469t of MB. The horticulture sector is of high importance to Turkey, not only because of large domestic consumption but also due to exports: in 2012 Turkish vegetable exports (largely tomatoes) were valued at \$967 million USD and flower exports (almost exclusively carnations) at USD \$30 million. The trials confirmed that soil-less production was a viable alternative for tomatoes, peppers and cut flowers, however, they also showed that due to high levels of expertise needed to make this system work, this option was best suited for more advanced growers, generally geared towards the export market. In particular, carnation and cherry tomato producers were able to successfully adopt this option (Yilmaz et al., 2006).

A key issue for the success of soilless culture is the identification of suitable, locally available and inexpensive substrates that keep costs of this technique within reasonable levels. Pumice was found to be a locally available, inexpensive substrate yielding very good results for carnation production in the region of Isparta, (Kazaz et al., 2009, 2010). Flower quality, as represented by stem length, flower diameter, vase life and stem diameter, was found to be significantly better than that of flowers grown in ground beds, fumigated with MB; yields were also improved and time from planting to flowering was reduced (Kazaz et al., 2009). It was however evident that an integrated crop management including close monitoring of watering, nutrition and environmental factors, were essential to the success of this technique. Additional technical and economic studies comparing soil cultivation with various types of substrates have been conducted in Turkey for other crops such as cucumbers, peppers and tomatoes, with similar results (Engindeniz, 2004; Sayin et al., 2010; Yilmaz et al., 2006, 2007).

Soilles production has also been trialled in Morocco through the MB alternatives project implemented by UNIDO and is proving to be a feasible alternative for growers in the region of Souss Massa with the required technical expertise. A slight increase in yield and a significant improvement in quality were obtained when growing tomato on coco fibre substrate, in comparison to traditional production in ground beds (UNIDO, 2013). This appears to compensate for an initial higher investment associated to substrate production; further trials are presently ongoing with the aim of adjusting water and fertilizer consumption.

CONCLUSIONS

Achieving 85% of the MB phase-out in developing countries ahead of the 2015 deadline has not been an easy feat. Since a one-to-one alternative to MB does not exist, changes in production strategies, process management and infrastructure have often been necessary, and often encountered reticence and scepticism from the part of growers and other stakeholders. Alternatives have been trialled and examined from the perspective not only of their technical feasibility, but also economic and commercial. Experience sharing amongst MB users from similar sectors in similar regions or countries has proven critical for the commercial adoption of alternatives. It is further evident that issues beyond the technical and economic feasibility of alternatives impact their long-term sustainability, for example being able to access specific market windows, but also regulatory issues, availability and supply of essential inputs and others.

Projects to phase-out MB have brought additional benefits: Training on alternatives has often lead to improved production and pest management strategies, and in many sectors, market headway is reported by previous users who have phased-out, given that environment-friendly production practices are much favored by consumers.

In synthesis, the overall clear lesson is that, regardless of MB, the goal is to develop successful pest management strategies, which are sustainable in the long term, with options available.

Literature Cited

- 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.
- Camacho, F., Ricárdez, M. and Huitrón, M.V. 2011. Watermelon and melon grafting in Colima, Mexico as an alternative to soil disinfection with methyl bromide. *Acta Hort. (ISHS)* 898:265-269
- Díez-Rojo, M.A., López-Pérez, J.A., Urbano-Terrón, P. and Bello-Pérez, A. 2010. Biodesinfección de suelos y manejo agronómico. Gobierno de España, Ministerio de Medio Ambiente y Medio Rural y Marino. Madrid, 408 pp.
- Francisco-Illescas, M.X. and Camacho-Ferré, F. 2009. El injerto en el cultivo de tomate como alternativa al uso de bromuro de metilo. Sonora- México 2009-2010. SEMARNAT-ONUUDI, México.
- García, R.A, and Camacho, F. 2011. Injertos hortícolas en el cultivo de tomate como alternativa al uso de bromuro de metilo en el grupo El Porvenir. Sonora, México 2010-2011. SEMARNAT-ONUUDI, México

- Huitrón-Ramírez, M.V., Ricardez-Salinas, M. and Camacho Ferré, F. 2009. Influence of grafted watermelon plant density on yield and quality in soil infested with Melon Necrotic Spot Virus. *HortScience* 44(7):1838–1841.
- Jácome, C. 2013. Alternativas al uso de bromuro de metilo en el cultivo de *Gypsophila paniculata* c.v. *cassiopeia* Guayllabamba, Pichincha – Ecuador. Sociedad Agrícola la Victoria SAVISA S.A. Informe final, Proyecto ONUDI.
- Kazaz, S., Yilmaz, S. and Sayin, B. 2009. Comparison of soil and soilless cultivation of carnation in Isparta province. *Acta Hort. (ISHS)* 807:547-552
- Kazaz, S., Yilmaz, S. and Askin, M.A. 2010. Effects of zeolite-peat mixtures on yield and some quality parameters of carnation grown in soilless culture. *Acta Hort. (ISHS)* 883:409-414.
- ITC, 2013. Market Analysis and Research, International Trade Centre, Geneva, Switzerland. [http://: www.trademap.org](http://www.trademap.org)
- Martínez, B., Figueroa, A., Baday, E. and Mejía, P. 2010. Uso de aislamientos de *Trichoderma* para el control de enfermedades en melón en Cholulteca. *Fitosanidad* 14(1):55
- MBTOC, 2007. Methyl Bromide Technical Options Committee. 2006 Assessment Report. UNEP, Nairobi, 424 pp.
- MBTOC, 2011. Methyl Bromide Technical Options Committee: 2010 Assessment Report. UNEP, Nairobi, 460 pp
- Michel, M. 2009. Implementación de un programa de eliminación de bromuro de metilo en la empresa Excotur. UNIDO Investment project on MB alternatives for melons
- Pizano, M., Miller, M. and Porter, I.J. 2010. Vision, developments and expectations in the horticultural sector in relation to the methyl bromide phase-out. *Acta Hort. (ISHS)* 883:49-56
- Reyes, A. 2013. Personal communication. UNIDO project, Honduras (presently in Guatemala)
- Ricardez-Salinas, M., Huitrón-Ramírez, M.V, Tello-Marquina, J.C. and Camacho -Ferré, F. 2010. Planting density for grafted melon as an alternative to methyl bromide use in Mexico. *Scientia Horticulturae* 126 (2010) 236–241.
- Sayin, B., Çelikyurt, M.A., Yilmaz, S. and Çelik, I. 2010. Economic evaluation of chemical and non-chemical soil disinfection applications for tomato production in Turkey. *Acta Hort. (ISHS)* 883:91-97.
- SEMARNAT. 2013. Estrategia para la eliminación del bromuro de metilo – experiencia en México. Workshop on alternatives to methyl bromide in strawberries and raspberries (fruit and runners). May 7-9, 2013 Guadalajara, Mexico. SEMARNAT (Secretary for the Environment and Natural Resources of Mexico)/ UNIDO
- TEAP, 2013. Technology and Economic Assessment Panel. May 2013 Progress Report. UNEP Nairobi, Kenya
http://ozone.unep.org/Assessment_Panels/TEAP/Reports/TEAP_Reports/TEAP_Progress_Report_May_2013.pdf
- Tello, J. 2013. Personal communication. UNIDO technical assistance project for the adoption of alternatives to MB.
- UNEP, 2013. Ozone Secretariat Data Access Centre, United Nations Environment Programme, Nairobi, Kenya
http://ozone.unep.org/new_site/en/ozone_data_tools_access.php
- UNIDO, 2005. Honduras: Phase-Out of methyl bromide in melon and banana production sector and tobacco seedlings. United Nations Industrial

Development Organization, Final Report. Secretaría Recurso Natural y Ambiente (SERNA), Honduras.

UNIDO. 2013. Project for the elimination of methyl bromide in cucurbits and green beans: 2012 annual report. Project No. MOR/FUM/62/INV/66 UNIDO, Vienna, Austria, 97 pp..

Yilmaz, S., Ünlü, A., Göçmen, M., Aydınşakir, 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 Research Conference on Methyl Bromide Alternatives and Emissions Reductions, San Diego, California, USA, October 29 – November 1, 2007.. pp.48-1 – 48-3.

Yılmaz, S., Ünlü, A., Gocmen, M., Mutlu, M., Aydinsakir, K., Fırat, F. F., Kuzgun, M., Celikyurt, M. A., Sayin, 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. BATEM/ UNIDO, Antalya, Turkey

Figures

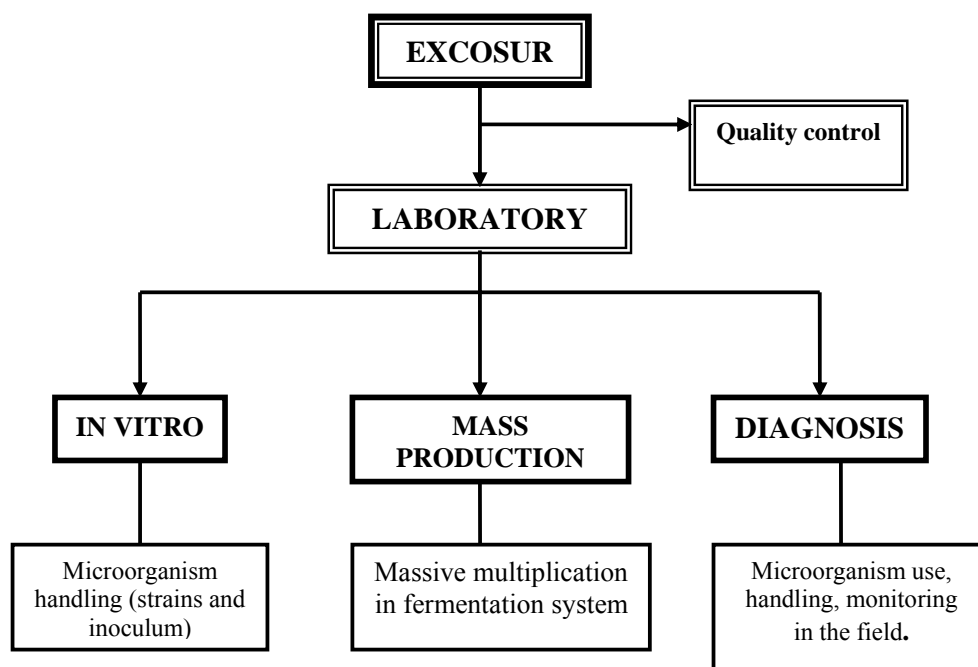


Fig 1. Laboratory design for massive multiplication of *Trichoderma* and *Bacillus subtilis* on a commercial melon farm (Excocsur) in Honduras. Source: Michel, 2009, UNIDO Investment project on MB alternatives for melons.