Global Report on Validated Alternatives to the Use of Methyl Bromide for Soil Fumigation

Cover photo
Alternative to methyl bromide: *Float System* (description on pages 17 - 24)

Global Report on Validated Alternatives to the Use of Methyl Bromide for Soil Fumigation

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PREFACE

Methyl bromide (MeBr) is a fumigant used to control arthropods, nematodes, pathogens and weed seeds in soil in several crops, such as tomatoes, peppers, eggplants, tobacco, strawberries, ornamentals and other crops.

Some years ago it was discovered that this fumigant is a strong chemical depleting the Earth's ozone layer. Its ozone depletion potential is 0.4, i.e. higher than the admissible threshold of 0.2. In addition, it is also known that bromine released by MeBr is 40 times more aggressive than chlorine in breaking down ozone on a per atom basis.

Governments and international agencies aware of the problem have agreed to establish a programme for phasing out the use of MeBr. Since the fumigant is used in several high-income crops the established phase out gives times to the countries for the development of new alternatives to replace MeBr.

During the last five-seven years some projects and activities have been carried out in several countries which had a high consumption of MeBr as a soil fumigant. The work has been applied field research for the development of new alternatives and demonstrations of those highly effective ones in large plots.

As a result of the above work there are available some published materials on new MeBr alternatives, which describe the feasibility and the disadvantage of each new pest control measure. Some of these publications have come out from several workshops and symposia organized in different countries by UNEP, UNIDO and other organizations.

The main purpose of the present report is to provide information of successfully used alternatives in some countries or regions, where MeBr phase out is going on. Although the report often shows the lack of already validated alternatives, particularly for a region like Africa, the material provides enough elements of the technical and economical success of the use of several alternatives as well as those, which are nearly to be introduced into the agricultural practice.

Agricultural researchers and extensionists could use this information for further studies and / or validation. This material, along with the Manual in preparation by FAO (sponsored by UNEP) [(1)], can also be a good reference for the training on new

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[(1)] R. Braga, R. Labrada, L. Fornasari and N. Fratini. Manual for Training of Extension Workers and Farmers on Alternatives to Methyl Bromide for Soil Fumigation. FAO Plant Production and Protection Paper N. (...) *In Prep.*

alternatives in different countries, particularly for Training of Trainers (TOTs). In addition, FAO / UNEP do hope that such a report and training activities, wich are part of the Farmer Education and Training Programme being carried out by FAO and sponsored by UNEP under the Montreal Protocol's Multilateral Fund, will also encourage the final validation of several promising alternatives to replace MeBr as soil fumigant. This will help developing countries to meet the MeBr phase-out requirements under the Montreal Protocol.

FAO / UNEP would also like to acknowledge and appreciate the contributions kindly given by several specialists from various countries from all over the world, which made possible the preparation of this global report.

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List of Acronyms

CPACT	Agricultural Research Center for Temperate Climate of EMBRAPA
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria (Brazilian Agricultural Research Corporation)
EPAGRI	
EU	European Union
DIVAPRA	(Italy)
ICM	Integrated Crop Management
FAO	Food and Agriculture Organization of the United Nations
IGR	Increased Growth Response
INTA	Instituto Nacional de Tecnologia Agropecuaria (Argentina)
IPM	Integrated Pest Management
KFC	...................spell out on page 75 !!!
LPDE	Low-Density Polyethylene Film
MAPA	Ministerio de Agricultura, Pesca y Alimentación (Spain)
MAFF	Ministry of Agriculture, Forests and Fisheries - Japan
MBOTC	Methyl Bromide Technical Options Committee
MeBr	Methyl Bromide
MITC	Methyl Isothiocyanate
MITI	Ministry of International Trade and Industry - Japan
NPSSS	Negative Pressure Soil Steam Sterilization
SINDIFUMO	
TOT	Training of Trainers
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
VIF	Virtually Impermeable Film

CHAPTER I: LATIN AMERICA

ALTERNATIVES FOR THE REPLACEMENT OF METHYL BROMIDE IN ARGENTINA

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Summary. Strawberry is an economically important crop in Argentina. Cropping of strawberry is variable in the regions of the country. Generally methyl bromide (MeBr) is applied as soil fumigant in the crops. Its use allows to protect the crop from the attack of several soil-borne pests. Several experiences have been carried out aiming at validating already tested alternatives and to adapt them for the replacement of MeBr. To this aim different chemical fumigants were compared. Dazomet and metam sodium were the fumigants compared for the control of soil-borne fungi, nematodes, insects and weeds. Both products came out as viable alternatives of MeBr.

In addition two other methods, soil solarization and water vapour, were also validated. The use of water vapour for soil disinfection is quite old. It consists of passing a vapour flow through the soil pores so that when entering in contact with cold particles are condensed, transforming itself into a liquid and releasing heat that allows the elimination of noxious living organisms. Water vapour was a little bit difficult to apply. The initial overall cost of its application may prevent its use. Some problems related to its application are not easily to overcome in current conditions. Soil solarization, consists of use of solar energy to heat wet soil previously covered by a polyethylene sheet. The method although effective in certain conditions, is not feasible to be applied everywhere. The area of La Plata is a suitable zone for the production of strawberry, especially for fresh consumption. All these control technologies can be well applied in strawberry fields of La Plata.

Tomato is also an important crop in the horticultural production of Argentina. Here again dazomet and metam sodium were effectively used as soil fumigants. Cropping practices of tomato vary from one zone to another in Argentina, and this may really condition the use of one or another fumigant. Obviously, aspects of economical feasibility of each chemical should also be taken into account to make the decision of their commercial use.

Cut flowers, carnation and lisianthus, are crops that occupy the most important ornamentals in Argentina. The areas of these crops are being increased every year. Dazomet and metam sodium showed the same effectiveness already quoted above for strawberry and tomatoes. These fumigants are potential alternatives to replace the present use of MeBr. The green belt of great Buenos Aires is the main area of production of these ornamentals.

Tobacco is another economically important crop in Argentina. The alternatives for the replacement of MeBr were evaluated in two systems: a) the conventional system using chemical fumigants as metam sodium and dazomet, and b) the soilless system using floating trays and supported trays. The results of this validation showed that any of these methods may satisfactorily replace the use of MeBr as soil fumigant for the control of soil-borne pests in tobacco seedbeds. Soilless systems have the advantage that, in addition to eliminate the use of MeBr, it provides uniform and vigorous crop seedlings. Additionally, these methods decrease the area necessary for tobacco seedling production.

Considering the existing results, it is concluded that the replacement of MeBr in strawberry,

tomatoes, tobacco and ornamentals is perfectly possible and feasible, either using a chemical alternative for seedbed desinfection or soilless systems in trays. The selection of any of these methods should necessarily take into account aspects of related to cropping techniques in each zone of the country, economical feasibility to farmers and environmental safety.

Key words: disinfection, floor, substratum, vapour, dazomet, metam sodium, soiless system, solarization

I. INTRODUCTION

The Project Ozone (MP/ARG/97/186 for horticulture and ARG/98/G63/INTA-PNUD for tobacco) was funded by UNDP and executed by INTA (National Institute of Agricultural Technology). It started in 1999, and its main objective was to evaluate various alternatives to methyl bromide (MeBr) for the control of soil-borne pests.

One of the main constraints to the agricultural production is the soil degradation, which is possible under monocropping conditions or short crop rotations, characteristics of the intensive production systems of vegetables, cut flowers and tobacco. The incidence of several soil-borne pests, particularly pathogens is also a constraint to the production of the above-mentioned crops. To avoid damage and losses caused by these organisms to these crops, soil disinfection has been constantly required.

MeBr has had wide diffusion in the world and in Argentina has been the most used soil fumigant. In recent years MeBr has been used largely in the country, e.g. horticulture consumes up to 280 tons annually, basically for tomato production, 230 tons in tobacco, 70 and 60 tons in cut flowers and strawberry, respectively.

MeBr is one of the main substances depleting atmospheric and its replacement is a need to protect the environment. The Government of Argentina has implemented a Program for the protection of the layer of ozone. Within the framework of this programme the projects MP/ARG/97/186 for horticulture and MP/ARG/98/G63/ INTA-PNUD for tobacco have been implemented in order to evaluate different alternatives, such as water vapour, soil solarization, soilless systems and other chemical fumigants.

II. EVALUATION OF THE ALTERNATIVES

2. 1. Strawberry is a commercially important crop in Argentina. The technology used for strawberry production in Argentina varies according to the regions. In general, soil to be used for cropping is treated with MeBr previous to planting. This practice, in addition to get rid off several soil-borne pests, preserves crop yields and its quality. Soil-borne pathogens currently cause important losses to strawberry. Conducted research in the past showed the benefits of soil fumigation for strawberry production. Serious reduction of yields has been observed in non fumigated areas of strawberry due to the severe incidence of soil-borne fungi.

Various experiments have been carried out in order to validate some alternatives to MeBr. They mainly consisted of comparisons of some chemical fumigants.

Dazomet is a granular product used at rate of up to 70 g / m^2 or 700 kg / ha. It is normally applied 30 days previous to planting. Granules are distributed uniformly on the soil surface then incorporated in the soil at a depth of 30 - 40 cm. After its incorporation the soil is irrigated and covered with a polyethylene sheet. For good effectiveness of the fumigant the soil has to be well prepared.

Metam sodium is a fumigant in liquid form, applied 30 days before planting. Soil is irrigated at 100 % of field capacity immediately after the application. Its rates are 125 cm^3 / m^2 or 1,250 litres / ha.

In both cases two different polyethylene films (40 or 80 microns thickness) were also evaluated.

The results showed that both fumigants were effective to control soil-borne fungi, nematodes, insects and weeds. They did not affect negatively plant stand, yields and quality of the fruit. In addition, both polyethylene films gave similar results of efficacy.

It was concluded that either dazomet or metam sodium are feasible alternatives to MeBr in strawberry in Argentina.

Other two methods tested were soil solarization and water vapour. The latter was a bit difficult to apply properly (see details in the section concerning vapour).

Soil solarization consists of using solar energy to heat the soil previously wetted and covered with a polyethylene film. The method although interesting, is not feasible to be applied every year. Its effectiveness is highly dependable on the prevailing environmental conditions, such as the air temperature, rainfall and others. One of the requirements for its effective application is to prepare the soil with good levelling and free of clods. The soil is then irrigated to field capacity and covered with a transparent polyethylene film (30 to 40 microns thickness). Solarization works well when air temperatures and sun radiation are high. The soil should remain covered with the film up to six-eight weeks. Soil solarization is an environmentally safe method, which in appropriate conditions eliminates harmful soil-borne organisms.

The area of La Plata is an important one in the production of strawberry, especially for fresh consumption. This is in fact the region where these new technologies can be well introduced and adapted.

2.2. Tomato is another important horticultural crop in Argentina. The techniques for cropping it vary from one region to another. In addition, tomato is one of the major consumers of MeBr in the country There is no doubt that the negative action of soil pathogens affect the production of tomatoes, and MeBr is the fumigant effectively used for the control of soil-borne pathogens. Soil disinfection with MeBr in tomatoes already started in the 40s.

Metam sodium and dazomet seem to be the main soil fumigants to replace the present use of MeBr.

Although they are well known products, it is necessary to adjust their rates and ways of application to make sure their success in tomatoes.

Formol is a solution, which contains 40 % of formaldehyde, which has been evaluated for its action against main bacterial diseases in tomatoes. This chemical, however, shows problems of human toxicity.

In field trials metam sodium was evaluated at the rate of 125 cm^3 / m^2, while dazomet was tested at 70 g / m^2 and formaldehyde 40 % (Formol) at 250 cm^3 / m^2.

After all these trials it was recommended to use these chemicals only when soil moisture is 40-70 % of the field capacity and temperatures between 18 and 24^{o}C. Soil, as usual, must also be well prepared. The treated soil surface should remain moisted from 7 to 10 days before the application. After the application the soil is to be irrigated with 5-10 litres of water / m^2 then covered with a polyethylene transparent film of 100 microns during the whole period of exposure. Before planting the polyethylene film is taken away and the soil is slightly removed for releasing remaining gas thus avoiding any possible gas phytoxicity.

The results obtained in these trials did not show significant differences among the treatments tested, i.e. dazomet at 70g / m^2, Vapam at 125 cm^3 / m^2 and formaldehyde at 250 cm^3 / m^2. Such results are similar to others obtained in strawberry in different parts of the world. These treatments are easy to apply either in strawberry or in tomato. In any case, the application of any of these four chemicals in tomato should be adapted to the characteristics of the soil and cropping practices in the different regions of the country. No less important is still to determine the economical feasibility of these chemicals.

2.3. Cut flowers, such as carnation and lisianthus, are the main ornamentals flowers in Argentina. The area of these crops has increased during the recent past. Production of these ornamentals can be used for internal consumption and for export.

One of the major constraints to this type of production is the negative incidence of diseases caused by *Fusarium* fungi. The pathogen is usually present in the soil and it is normally resistant to adverse conditions that allow it to remain for longer periods in the soil. It is also able to survive conditions of stress as water excess and drought. The fungus is also tolerant to various pesticides. A combination of factors in soil, still to be precisely determined, brings about the infection of the crop at different growth stages, causing high plant mortality and huge reduction of the production.

Results of recent survey in greenhouses of ornamental production report that disease caused by *Fusarium* is present in 100 % of the areas. This problem with others related to ornamental production compels to use MeBr as soil fumigant in greenhouses.

Research conducted recently clearly showed the possibility to use successfully other control methods for soil disinfection, such as the dazomet, metam sodium and water vapour. Soil solarization is an useful method, but with limitations if environmental conditions of the season change, i.e. low air temperatures and heavy rainfall.

Due the increased use of MeBr and the problems caused by diseases, some alternatives were evaluated, such as dazomet, applied at 70g / m^2, 36 days before planting. The soil was covered with a polyethylene transparent film of 50 microns during 21 days after the application. The film was then removed to allow the release of gases still remaining in the soil. Metam sodium at rate of 125 cm^3 in 5 litres of water / m^2 was applied 36 days before planting. Then the same steps as described for dazomet were followed.

Water vapour was applied 15 days before planting with a machine for sterilisation Sterilter 50, endowed with a tank of 50 litres of capacity, burner, tank of fuel and a dosificator of vapour. Soil temperature in the first 15 cm, immediately after the application, oscillated between 50 and 90^oC.

After the application of these treatments, tests were made to evaluate their control over *Fusarium*. There was no significant differences among the treatments.

Crop productivity, i.e. flower production, was also similar among the treatments. Dazomet and metam sodium showed nearly the same effect, which was better than water vapour. Both products can be considered as alternatives to MeBr in ornamentals.

The green belt of Great Buenos Aires is the main area of production of cut flowers in Argentina. Although these are relatively recent, areas have increased, so at this point, new alternatives will undoubtedly used in the near future to effectively replace MeBr.

Water Vapour is an old method for soil disinfection. It consists of passing a flow of vapour through soil pores or any other substratum, that when taking contact with the cold particles it condenses, transforming itself into liquid and releasing heat, which destroys several noxious living organisms. It is well known that the tolerance and / or susceptibility of these organisms depend on their physiological state at the time of the treatment. One aspect is also the temperature to be provided by the vapour in soil. Temperatures of 70-75^oC are lethal to many harmful organisms, but undesirable if to preserve useful flora and fauna in soil. Temperatures of 60^oC can be enough for the control of most of soil-borne pathogens, nematodes and seeds.

The effectiveness of the use of vapour of water depends on several factors, as temperature, the uniformity of its distribution, soil depth that vapour reaches, etc. Good effectiveness is also dependable on time of application and the quality of land preparation. Vapour should also reach 10-16 cm soil depth to be effective enough.

The system generally consists of achieving the exchange of heat among the hot gases released from the burner impelled through the body of the boiler. The commercial boilers are operated through electricity or with fuels. The mobile boilers of the Project MP/ARG/97/186 used gas-oil because of its availability in rural areas. After analysing the offer of various boilers in the market, it was decided to use TX-40 of 3 bar of pressure and 400 kg per hour of vapour generation for application with badge.

For soil application two methods were tested: a) low carp of plastic or canvas, which distribute the vapour by means of tube-diffusers placed in soil; b) with mobile badge mounted to the tractor.

The system with mobile plate presents advantages in productivity, since it is able to treat large areas at reduced cost than the system of application using a carp.

Although the cost of vapour application with mobile plates is more expensive than the application of MeBr, it is a viable alternative. It controls a wide spectrum of soil-borne pests and it effectively protects crop of tomatoes and strawberry.

2.4. Tobacco is grown in seven counties in Argentina. In the last two years national annual production was about 113.000 tons and the value of the production is US$220-230 million. Two systems were evaluated as alternatives for the replacement of MeBr in tobacco production: a) in the conventional system, which includes use of either soil fumigant metam sodium and dazomet, and b) the soilless systems, which includes the evaluation of floating trays and supported trays.

In the conventional system two fumigants were applied in conventional seedbeds, that is to say, seedbeds built on the level of the floor whose borders were built with plywood and stakes. A layer of forest organic soil was deposit on the seedbed surface, previously sieved to separate the sticks and roots of trees.

Seven days previous to the application of metam sodium the seedbeds were abundantly watered and covered with a carp of transparent plastic to stimulate biological activity in the soil. Methan sodium was applied at rate of 100 cm^3 / m^2. After its application, it was incorporated a little more water and the seedbed again was covered with the plastic during the next 28 days. After this period the seedbed was uncovered and left for aeration during another 12 days.
Dazomet was also applied similar to metan sodium. Its rate of application was 50 g / m^2. Just after its application on the soil surface it was incorporated using a hoe and followed by another abundant watering. Later the seedbed was covered with a plastic film for 28 days, then uncovered and left for aeration during 12 days.

Planting density was the same one used in the region (0,15 g of raw seeds / m^2). After planting, a light irrigation was made and the seedbed was covered with a transparent plastic of 80 microns.

The evaluation of germinated plants and crop stand and development showed that MeBr effect is far better than the one given by both new fumigants. In any case, metam sodium and dazomet showed some degree of soil disinfection, but not equal to MeBr.

The advantage here is that Metan sodium and dazomet are less toxic than MeBr, which makes them easier to handle and much safer for humans. Metam sodium application is 40 % much cheaper than dazomet. However, both fumigants, probably due to some level phytoxicity, presented reduced crop seedling stand and low effect against soil-borne fungi. The fumigants were effective against nematodes and weeds.

The soilless system allows the production of tobacco seedlings without the need of use MeBr, since the substrate is guaranteed pest and disease-free and contains the main nutrients required for optimal plant growth.

The soiless system developed for tobacco is an opened hydroponics, where the solution with nutrients is not always recycled.

Seedling production through this system is carried out in plastic pools of 10 m long, 1,20 m wide and 10-15 cm height. It is important that the land in the pools be well levelled covering the surface with a layer of 2 cm of sand to avoid punctures in the plastic. The borders can be built with diverse materials (wires, plywood, bricks, others). The covering of the internal part of the pool is carried out with black plastic of no less of 200 microns. The pool is full with clean water until it reaches 3-5 cm of the superior border. The pool is protected by a micro-tunnel of transparent plastic UV of 150 microns, which is kept by iron arches of 6 mm diameter. The plastic was fixed to both ends by stakes placed one meter of the head of the pool. The pools has to be opened often. The dimensions of the pools can be changed according to the size of the greenhouse.

Tobacco planting is carried out in styrofoam trays with 288 small cells per tray, previously filled in with a sterilised substratum. Pelletized seeds are used, which favours better distribution at the time of planting. Trays are placed in the pool and left floating during 60-80 days until the seedlings are well developed. During this period the seedlings are regularly checked, especially the whole pool system ventilation (open during the day on the lateral up to 15 cm of height and closed at night), maintaining constant the level of water, fertilising the water (15N 10P 15K or 20N 10P 20K), using foliar treatments for pest control (Confidor, Carbendazim, Iprodione, Kasugamicina, Agrimicina and others) treating water with copper hydroxide, and pruning the plants three times.

The pools of supported trays system are smaller (4 x 1 x 0,5 m) than those used in common floating trays. Its walls are built with bricks. In this system plastic tray of 50 x 33,5 x 0,5 cm, with 150 cells each one, is used. The pool is filled in with water and due to the fact that plastic trays do not float, it is supported by the plastic, immerses in a volume of water that arrives to 2 cm height. The reposition of water to keep the required level is constant.

The handling and managing procedures of the supported tray and floating tray systems are basically the same thing, with very few variations, such as in the supported trays it is carries out only two prunings.

Of soilless systems, the system of supported plastic trays presents additional advantages, such as the seedling development cycle is shorter (10 days), seedlings with better root system, easy removal of seedlings from the trays, better managing of the trays, smaller storage space and bigger durability. The disadvantage is the biggest initial cost of acquisition and bigger care with the reposition of the water in the pool.

Validation of these alternatives demonstrated that they can replace the present use of MeBr in tobacco seedling production.

Considering the evaluated systems, technically it is evident as more appropriated the soilless systems, since besides the elimination of MeBr, it represents a technological progress for producing uniform seedlings for their quick establishment in the field and to establish more homogeneous plantations. Additionally, it decreases the necessary considerable space for seedling production (75 % less surface).

Any of these systems of seedling production in trays can be adopted for tobacco seedling production in Argentina.

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EFFECTIVE ALTERNATIVES TO METHYL BROMIDE IN BRAZIL

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Summary. Three validated alternatives to the use of MeBr for soil fumigation are presented: (1) solarization of conventional seedbeds; (2) the use of metam sodium in conventional seedbeds; and (3) the "floating trays" system. Solarization proved to be a technically feasible and cost-effective non-chemical alternative to MeBr to produce healthy and adequate seedlings. Metam sodium is a very good alternative, too. It is very easy to apply, practically odorless, and it is safer and easier to use than MeBr. The float production system produces tobacco seedlings for transplant that are of greater uniformity, with a much stronger root system and at reduced labor costs.

Key Words: methyl bromide, alternatives, solarization, metam sodium, soilless cultivation, floating trays

I. INTRODUCTION

Crops grown in soil, including tobacco, are exposed to soilborne pathogens (fungi, viruses and bacteria), nematodes, arthropods and weeds. As a method of treatment against a wide range of pests, MeBr is used in many geographical regions of the world. MeBr appeared on the market in the 1930s and has been used in Brazil for more than five decades. Its largest use is in tobacco seedbeds, accounting for more than 95 % of Brazilian use of this pesticide. The widespread use of this fumigant has been encouraged by its simple mode of application and technology needed.

In the early 1980s the connection between halogenated hydrocarbons and the destruction of the ozone layer in the stratosphere was made and later it was confirmed that MeBr was also implicated in this phenomenon. Considerable evidences have been accumulated that MeBr is a potent ozone depletor and the possibility of eliminating this fumigant from agricultural use was strongly considered since then.

There is still general consensus that, because of its versatility, there is no single alternative chemical treatment, or combination of treatments, that at present can fully substitute MeBr. However, alternatives to its use are currently available for specific problems and additional alternatives may be developed using non-chemical methods, new organic amendments, biological control, cultural practices, and physical and chemical methods. Many of the alternatives to be used should be part of an overall integrated pest management system and should also be combined with other pest control tactics to achieve an economically sustainable method of management.

To find new technologies in order to avoid the use of MeBr in tobacco seedbeds was the objective of the demonstration project jointly developed by EMBRAPA, EPAGRI, SINDIFUMO and UNIDO during the years of 1998, 1999 and 2000. This project was joined by the effort of the Brazilian tobacco sector to find economical and technically feasible alternatives to the use of MeBr for production of tobacco seedlings. The field work was carried out in the tobacco production regions in Rio Grande do Sul and Santa Catarina. These two states are located in the southern part of Brazil, between latitudes of 23 and 32ºS.

This document describes, in addition to the conventional seedbeds, three validated and most promising alternatives developed by the Brazilian tobacco companies and by the EMBRAPA / EPAGRI / SINDIFUMO and UNIDO cooperative project:

a) solarization of conventional seedbeds;
b) use of metam sodium in conventional seedbeds; and
c) "floating trays"system.

II. CONVENTIONAL TOBACCO SEEDBED

The traditional tobacco nursery, or seedbed, in southern Brazil is made directly on the soil, measuring 25 m long by 2 m wide. The soil is risen of 10 - 15 cm above the ground level.

Due to the fact that weeds, soilborne pests and diseases are common in the tobacco areas, it is necessary to suppress those potential pest problems in order to produce an acceptable quantity and quality of seedlings. For this purpose, the fumigant MeBr has been used for fumigation of the tobacco seedbeds.

Seedbed installation should be leveled and the soil well prepared free from clods, undecomposed roots and stalks, and with enough moisture. If the soil is excessively wet, it is necessary to wait until it reaches ideal moisture or, if very dry, it is necessary to water uniformly; to build a contour segment (barrier) on the surface of the seedbeds, to avoid flash flooding.

Prior to punching bromide cans (680 g per can), transparent plastic anti-UV 100-micra sheet should be kept stretched for at least three days. It is not desirable to start seedbed treatment if room temperature is below 10°C. It is convenient to allow the seedbed to be fumigated for at least three days. Sowing (3.5 g of raw seeds per seedbed) should be done only after 2 days elapsed from removal of plastic sheet.

A plastic film is constantly used on the seedbed to protect the emerging and young seedlings from sunburn, adverse temperatures, wind, rain, etc.

Control of foliar diseases, such as alternariose, yellow stunt, sore shine, damping off, sclerotinia rot, is currently done with fungicides (thiabendazole, mancozeb, iprodione, maneb) sprayed every week or just after a rainy day. Control of insect pests is not normally required in the seedbed. Snails are locally potential problems.

Despite of potential problems pointed out due to the use of MeBr, labor intense use, quality of seedling, etc., conventional tobacco seedbeds are still used and preferred by a large proportion of tobacco growers in the south of Brazil. It is considered a very cheap process and with an adequate cost-benefit ratio (Table 1).

Table 1. Cost of production (in US$) of seedlings for one hectare of tobacco with conventional seedbeds with methyl bromide (source: EMBRAPA / EPAGRI / SINDIFUMO / UNIDO project, 1998 - 2000)

Item	Unit	Quantity	Duration	Unit cost	Total cost
Plastic-fumigation	m^2	143	2	0.21	14.71
Plastic-rainmay	m^2	143	2	0.06	4.49
Methyl bromide	Can	5	1	3.89	19.49
Fertilizers	Kg	25	1	0.21	5.43
Seeds	Pack	2.5	1	1.71	4.29
Iprodione	Kg	0.11	1	54.67	6.12
Mancozeb	Kg	0.45	1	9.73	4.38
Imidacloprid	Pack	0.5	1	8.62	4.31
Labour	W / h	75.6	1	0.68	51.84
Total					**115.06**

III. CONVENTIONAL SOLARIZED SEEDBED

In the conventional seedbed, the soil is irrigated until its saturation, to improve heat transportation in the soil profile, and covered with anti - UV 100µm transparent plastic, during a period of at least 60 days. Normally, the plastic is left in its place during the summer, laid in February and removed just before the sowing period, i.e. by May. After the period of solarization, the plastic is removed and the area is sowed. Before sowing the soil is revolved only superficially. Control of disease, insect pests and snails are done as explained for the conventional seedbeds.

Solarization is a process which, due to the diversity of conditions, requires more research and development of the methodology, the type of plastic film, the period of application, etc. In southern Brazil, which has a temperate climate, temperatures reach up to 60ºC at 10 cm of depth, which is high enough to kill the most common weeds and soilborn pests.

It should be mentioned that solarization could be a complicated process for use on a large scale. The effectiveness of this method is directly linked to climate, that is, the amount of sunlight received during the solarization process. It should be an ideal method for tropical climates. It is considered a very cheap process and with an adequate cost-benefit ratio. Solarization showed the lowest cost among alternatives studied in southern Brazil (Table 2).

Overall, solarization proved to be a technically feasible and cost-effective non-chemical alternative to MeBr, to produce healthy and adequate tobacco seedlings.

Table 2. Cost of production (in US $) of seedlings for one hectare of tobacco with conventional solarized seedbeds (source: EMBRAPA / EPAGRI / SINDIFUMO / UNIDO project, 1998 - 2000)

Item	Unit	Quantity	Duration	Unit cost	Total cost
Plastic-solarization	m^2	143	2	0.26	18.79
Plastic-rainmay	m^2	143	2	0.06	4.49
Fertilizers	kg	25	1	0.21	5.43
Seeds	pack	2.5	1	1.71	4.29
Iprodione	kg	0.11	1	54.67	6.12
Mancozeb	kg	0.45	1	9.73	4.38
Imidacloprid	pack	0.5	1	8.62	4.31
Labour	W / h	75.6	1	0.68	51.84
Total					**98.55**

IV. CONVENTIONAL SEEDBED USING METAM SODIUM

Metam sodium is a broad spectrum soil fumigant that is used to control nematodes, weeds, and fungi affecting a variety of economically important fruit and vegetable crops. In general, metam sodium is considered a technically sound and cost-effective alternative to MeBr to control pests in the soil which affect high value fruit and vegetable crops. This fumigant is readily available, moderately toxic and versatile and has been used in a variety of commercial applications to treat soils prior to planting for the control of annual weeds, nematodes and soilborne pathogens.

Metam sodium is a water-soluble liquid that after having been applied to the soil becomes a gas. It is applied in the conventional seedbeds at a rate of 75-80 ml / m^2, and the soil is covered with a plastic film during 4 to 5 days, to improve the fumigation effect. Prior to the application, soil moisture is increased by irrigation. It could be applied with ordinary back sprayers, or watering cans.

When the plastic is removed, the soil must be revolved (up to 15 - 20 cm of depth) to release possible gases that remained in the soil. A safe interval for waiting is from 7 to 21 days, after the plastic is removed, before planting, depending on the amount of organic material and the temperature of the soil.

Metam sodium is a very good alternative to MeBr, especially for farmers who want to continue to use chemicals for soil desinfection, or sterilization. It is a very easy product to apply, practically odorless. Metam sodium is safer and easier to use than MeBr.

One of the greatest advantages attributed to the use of metam sodium is the low cost. However, the cost of seedlings produced with metam sodium in southern Brazil was practically equal to that of seedlings obtained with MeBr (Table 3). It is possible to speculate that metam sodium still has a higher price due to its small scale of commercial use.

V. FLOATING TRAYS ("FLOAT") SYSTEM

Currently, in the state of Rio Grande do Sul, south of Brazil, 60 percent of tobacco seedlings are produced with the float system. This system also prevails in Santa Catarina, the second largest tobacco-producing state.

The tobacco sector is rapidly shifting from the outdoor seedbed method, which requires fumigating the soil (with MeBr), to on-farm plastic houses, which use floating trays and the soilless system. The shift is occurring primarily because seedlings grown in

Table 3. Cost of production (in US $) of seedlings for one hectare of tobacco with metam sodium in conventional seedbeds (source: EMBRAPA / EPAGRI / SINDIFUMO / UNIDO project, 1998 - 2000)

Item	Unit	Quantity	Duration	Unit cost	Total cost
Plastic-fumigation	m^2	143	2	0.26	18.79
Plastic-rainmay	m^2	143	2	0.06	4.49
Metam sodium	l	8.43	1	1.83	15.41
Fertilizers	kg	25	1	0.21	5.43
Seeds	pack	2.5	1	1.71	4.29
Iprodione	kg	0.11	1	54.67	6.12
Mancozeb	kg	0.45	1	9.73	4.38
Imidacloprid	pack	0.5	1	8.62	4.31
Labour	W / h	76.6	1	0.68	52.52
Total					**115.74**

[PAGE WITH FIGURES 1 –3]

plastic houses are less labor intensive and therefore can be cheaper over the long run. It is estimated that 75 % and 100 % of tobacco seedlings will be produced in plastic houses in southern Brazil by the season of 2000 / 01 and 2003 / 04, respectively. A big advantage of this system is the fact that the production of tobacco seedlings requires 50 to 60 days until they reach a height of 15 - 20 cm. In the conventional seedbed three months are necessary for seedlings to complete their development.

There are two types of plastic house production systems; the direct-seeded float system in low and in the high tunnel. However, usually the high tunnel is not being adopted due to the currently very high costs for its construction. The float system in low tunnel is the most common system and is used by approximately 60 % of tobacco growers in southern Brazil. The float system uses commercially prepared and sanitized media. The most commonly used media preparation contains fermented pine barks, expanded vermiculite and perlite. In brief, the float is a way to grow seedlings developed in styrofoam trays, with special media, where the seedlings are grown in a pool with water.

The construction of the float system should begin with the pool. The float should be built next to the farmer's house, on a well ventilated site, with good sunshine exposure and on a level surface. To build the pool, the first thing to do is to level the surface and to construct the four sides of the pool using 10 cm high bricks (Figures 1 and 2). A complete pool module has 10.55 m long by 1.45 m width and 10 cm high. A black plastic is put insight and over the pool edges and the pool is filled up with water. Water quality is extremely important and fundamental to prevent seedbed diseases. Therefore, only use drinking water treated with copper sulfate upon placement in the float bed. The outside edges of the black plastic are covered with soil (Figures 3 and 4). Eleven wire arches, 1.06 m apart and 0.90 m high at the center of the pool, are fixed just beside the lateral pool edges (Figure 4). Four wood stakes are fixed at both ends of the pool to support the wire arches and the plastic. The top of the stacks, as well as any sharp end, should be covered with ordinary plastic, or other material to protect the plastic covering (Figure 5). Anti - UV 100 µm transparent plastic is expanded along one side of the pool and then expanded over the arches. The plastic edges are fixed with small stacks at the end of the pool (Figure 6). Eleven rubber strips are used to tighten the plastic tunnel over the arcade. It is used one rubber strip on each wire arch site (Figure 7). Tobacco seedlings are produced in 200 cells styrofoam trays (34 x 68 x 6 cm) that are maintained floating in the pool. To prepare the trays, the first step is to wet the media as desired. The media is put on the trays and slightly compacted by shacking or knocking the tray. The media leftover is taken out of the tray. Seeding, with a special seeder tray, is done in half of the tray with only one coated seed per cell and inverting the tray position, repeating the operation again at another half of the tray but putting two seeds per cell to prevent enough seedlings for possible transplant. When the tray is seeded it is ready to be put in the pool (Figure 8). The water level in the pool should be maintained at 3-5 cm of depth. Fungicides and algaecides (e.g. thiabendazole, mancopper, iprodione, mancozeb) are periodically sprayed and added in

the water to prevent fungal diseases and development of algae (Figure 9). Aerial clipping is started when seedlings are 5 cm tall and repeated once, or twice. Clipping tools are disinfected with soap and water before use, or reuse. Clipping should be done outside of the pool area. Clipping makes the seedlings uniform, stronger and more resistant. For the success of the float, two aspects should be considered carefully: ventilation and fertilization. For a proper ventilation it is necessary to keep the sides of the plastic open during the day and closed only during the night, or in days with strong winds, or rain (Figure 10). Another aspect is the strict control of water fertilization. Five hundred grams of the fertilizer (20N, 10P, 20K) should be added to the pool every 10 - 15 days, as shown in Figure 9. In a complete pool module, 10.55 m long by 1.45 m wide, 60 styrofoam trays are housed and more than 10,000 usable seedlings could be produced (Figure 10).

The float production system produces tobacco seedlings for transplant that are of greater uniformity, with a much stronger root system and at reduced labor costs.

Switching from the conventional system to produce seedlings to the float system results in some difficulty to quantify benefits, such as more uniform transplants, much stronger and abundant root system, less replants and possible savings, that offset a slight increase in production costs (Table 4).

Table 4. Cost of production (in US$) of seedlings for one hectare of tobacco with float system in low tunnel (source: EMBRAPA / EPAGRI / SINDIFUMO / UNIDO project, 1998 - 2000)

Item	Unit	Quantity	Duration	Unit cost	Total cost
Styrofoam trays	un	100	5	1.68	33.60
Manual seeder	un	1	10	51.20	5.12
Wire steel arches	un	16	5	1.14	3.66
UV plastic	m^2	47	2	0.26	6.18
Rubber bidders	un	16	2	0.34	2.79
Lumber	m	38	3	0.37	4.70
Nails	kg	0.5	3	1.02	0.17
Black plastic	m^2	42.3	1	0.33	14.26
Substrate	kg	165	1	0.17	29.23
Coated seeds	un	21 700	1	0.0006	12.40
Fertilizers	kg	4	1	0.21	0.87
Copper	kg	0.12	1	4.14	0.50
Iprodione	kg	0.01	1	54.67	0.87
Labour	W / h	48	1	0.68	32.91
Total					**147.65**


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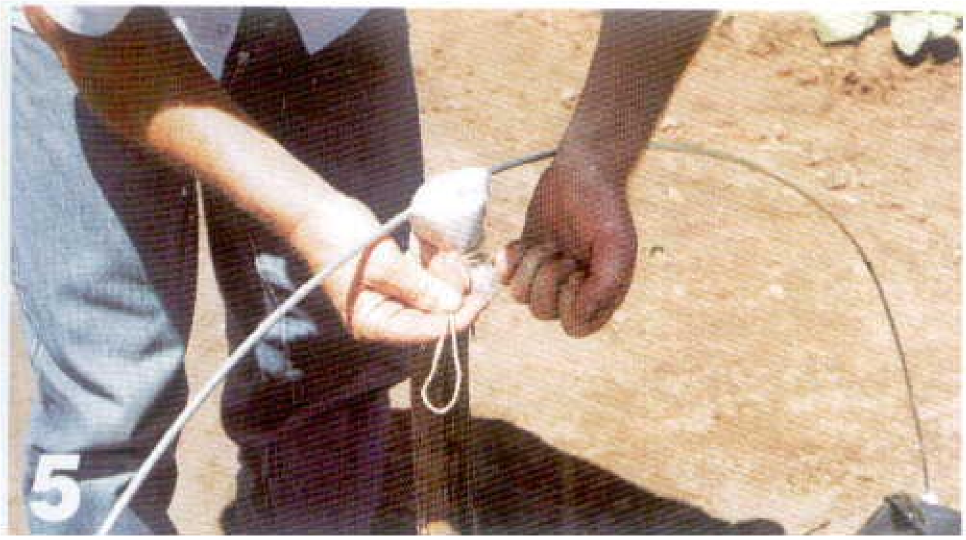
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Increased costs associated with float production include a greater capital investment than required by conventional growing practices. Float also requires more management than conventional growing systems to be successful. However, float production reduces labor needs, primarily for the person pulling up seedlings, boxing them, and transporting them to the field for transplantation.

Production costs for conventionally grown tobacco seedlings for one hectare were US$ 115.06 with MeBr, US$ 115,74 with metam sodium and US$ 98.55 with solarization. With the float system in low tunnel the production cost was US$ 147.65.

Adjustments in current float system, such as the size, materials and management may also result in additional savings. For example, as the size of the tunnel increases, the costs of producing tobacco seedlings decrease. Different management techniques can also reduce the difference in costs.


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CHAPTER II: NORTH AMERICA

FIELD VALIDATION OF METHYL BROMIDE ALTERNATIVES IN FLORIDA FRESH MARKET VEGETABLE PRODUCTION SYSTEMS

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Summary. Several alternatives to methyl bromide (MeBr) have been validated in vegetable production systems in the southeastern United States. All of the alternatives have demonstrated the potential to replace MeBr in the specific cropping systems in which they were evaluated. However, all alternatives lack the same broad spectrum of control achieved with MeBr fumigation and have more stringent application requirements. Thus, additional knowledge of pest biology and application technology is required by the growers to implement these alternatives. Growers must also cope with the management of additional information and a more complex decision making process regarding the selection and implementation of alternatives.

Key words: methyl bromide, chemical alternatives, solarization, cultural prcatices, strawberry, pepper, tomato

I. INTRODUCTION

Florida is the leading producer of fresh market tomatoes and pepper in the United States. Combined these two commodities comprise 23,760 ha and produce over US $745 million worth of tomato and pepper. MeBr fumigation is conducted on 93 % of the tomatoes and 83 % of the peppers grown in Florida and together they account for 25 % of the total consumption of MeBr in the United States and 8 % of the global methyl bromide consumption.

A closer examination of the crop production systems used in Florida is necessary to understand many of the constraints impacting the development of alternatives to MeBr. Since the 1960's, growers have used a production system in which seedlings are transplanted into pre-formed 76 - 100 cm wide by 20-25 cm high beds that have been fumigated with methyl bromide and covered with polyethylene plastic. MeBr is applied to the raised beds by shank or chisel injection methods. A high level of inputs is required to sustain economic yields. Preharvest production costs can exceed $16,000 per ha while expected yields in tomato can reach as high as 2300 kg / ha. Land suitable for these production systems is limited and associated rental costs are high, forcing growers to practice as sustained monoculture over many years. This in turn escalates the build-up and subsequent damage inflicted by soilborne pests.

II. CHEMICAL ALTERNATIVES

Since 1996, the University of Florida has conducted 69 large scale field demonstration trails of chemical alternatives to MeBr. Thirty-six were conducted on tomato, 28 on strawberry and 3 on pepper. Each demonstration trial was conducted on a commercial area by the grower. The minimum size for treated areas was 0.2 ha. Attempts were made to collect crop yield information independently from two sources: 1) small research subplots and 2) grower pack-out from entire treated blocks.

The alternative fumigants evaluated were various mixtures of 1,3-dichloropropene and chloropicrin. In addition, the herbicide pebulate was included in the tomato trials and the herbicide napropamide was included in the pepper trials.

Using data collected from grower pack-out, the average loss in the alternative plots was 1.12 % when compared to the MeBr treated plots (Noling and Gilreath, 2000). In the 12 trials were yield data was collected from the grower, the alternative treatment had higher yields in 3 trials and methyl bromide resulted in higher yields in 9 trials. Disease and nematode pressure was low in all of the trials. Problems were encountered with soil incorporation of the herbicides and phytotoxicity was observed when pebulate was not thoroughly mixed into the soil prior to planting. Recently, trials have been implemented using broadcast applications of 1,3-dichloropropene plus chloropicrin to avoid problems associated with worker exposure and requirements for workers in the field to wear full protective clothing. A deep placement 76 cm coulter system has been adapted to optimize fumigant diffusion patter and retention when compared to tradition shank injection systems.

III. NON - CHEMICAL ALTERNATIVES

Since 1995 soil solarization has been validated in 21 large scale demonstration plots in commercial production farms by the U.S. Department of Agriculture, Agricultural Research Service. The minimum size for treated areas was 0.2 ha. Attempts were made to collect crop yield information independently from two sources: 1) small research subplots and 2) grower pack-out from entire treated blocks.

In addition, additional large-scale field plots were established to evaluate various mixtures of 1,3-dichloropropene and chloropicrin at low rates in combination with soil solarization.

Soil solarization practices were modified to be compatible with the standard crop production systems. Strip solarization was performed on raised beds using clear, low density polyethylene film or clear, virtually-impermeable-film. Following a six to eight week solarization period, the film was painted white with latex paint to allow it to function as horticultural mulch.

In tomato, average marketable yields in the solarization treatments were 5 % less than the adjacent MeBr fumigated plots. In pepper, average marketable yield were 2 % less than adjacent methyl bromide fumigated plots. When solarization was combined with deep disking down to 25 cm depth prior to application of the plastic, yields were 23 % greater than adjacent methyl bromide fumigated plots. In plots were solarization was combined with low rates of alternative fumigants, yields were 13 % than in the adjacent methyl bromide fumigated plots.

Solarization was found to provide adequate control of weeds including yellow and purple nutsedge. Disease pressure was low in all plots. Solarization did not provide acceptable levels of control for root-knot nematodes. Technical problems associated with application of solarization included failure to provide adequate paint coverage to the plastic following termination of the solarization period. This resulted in excessive heating of the soil and some damage to the subsequent crop. Drip irrigation tubing was melted by the solarization treatment when tubing was placed directly on the surface of the soil beneath the plastic film. This problem was corrected by burying the tubing at to a depth of 5 cm.

Variability in results in the solarization treatments can be attributed to the complex mode of action of solarization and the influence of ambient conditions. Solarization works through a combination of physical, chemical, and biological changes in the soil profile. Many of these changes depend on soil type, moisture, and resident microbial populations. Additionally, thermal inactivation is a function of time and temperature and varies depending upon the ambient conditions during the time of solarization. Thus, it is not possible to prescribe a precise treatment period that will provide a broad level of control prior to application. This in turn creates a level of uncertainty among growers and remains one of the biggest factors impeding the widespread adoption of soil solarization. Soil solarization should not be perceived as a stand-alone replacement to pre-plant fumigation with MeBr for soil disinfestation due to problems with consistency of a range of environmental conditions and cropping systems. However, soil solarization is compatible with most nonchemical methods for pest management and deserves serious consideration as a fundamental component of pest management programs that use the biological knowledge of pests to select and integrate tactics promoting safe, profitable, and durable pest management. Its importance and potential contributions to IPM programs have been discussed

IV. ALTERNATIVE PRODUCTION SYSTEM

The benefits of crop rotation and minimum tillage were incorporated into an alternative production system by designing a low-input production system for tomato using minimum tillage practices in existing Bahia grass pasture. Florida alone has over 2.5 million acres of improved Bahia grass pasture. Through a design that is compatible with pasture crops, the alternative system increases access to those pastures. In addition to reducing input costs, minimum tillage techniques conserved the integrity of the mulches.

The alternative production system was validated in a 3 ha demonstration plot established by a commercial tomato grower. Comparisons in pest pressure, production costs, and marketable yields were made in an adjacent 3 ha plot fumigated with MeBr. Marketable yield in the alternative production systems was 36 tons per ha as compared to a yield of 42.5 tons per ha in the methyl bromide fumigated plot. However, production costs were reduced by $2000 per ha in the alternative production system. Thus, the net return (per ha) was $2888 in the alternative production system and $2320 in the conventional production system. The results demonstrated that profitable yields can be obtained in a vegetable production system designed to meet several environmental and economic goals.

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CHAPTER III: SOUTHERN EUROPE

ALTERNATIVES TO METHYL BROMIDE FOR SOIL FUMIGATION IN SPAIN

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Summary. Until 1998, Spain was the fourth country in the consumption of MeBr in the world, with a total of 4,191 t used. MeBr was applied as a soil fumigant to 8,988 ha of various crops, mainly strawberry (33 %), pepper (29 %), cut flower (9 %) and cucurbits (9 %). To reduce the consumption of MeBr, it is recommended the application of reduced dose (20-40 g / m^2) under virtually impermeable film (VIF), and formulations of MeBr with a high content of chloropicrin (35–50 %). Among chemical alternatives, the combination of 1.3 dichloropropene (1.3-D) plus chloropicrin, dazomet, or reduced doses of metam sodium have been demonstrated to be as effective as MeBr when applied with solarization. Among the non-chemical alternatives, biofumigation and solarization are outstanding, and so are soil-less cultivation, crop rotation, resistant varieties, and grafting, which are effective means of control when included in an integrated crop management system (ICM). The alternatives cost less, are as effective as MeBr, and do not pose problems in application.

Key words: strawberry, pepper, vegetables, cut flowers, biofumigation

I. INTRODUCTION

The date of elimination of MeBr in Spain, as an EU member, is in the year 2005, except for critical uses, whenever conclusive technical, economic and social reasons are indicated. There will be a gradual withdrawal of up to 60 % in the year 2001 and up to 75 % in 2003, since the remaining 25 % should have been withdrawn in 1998. It should be remembered that the use of MeBr in Spain, for control of pathogens in vegetables, is centered on a limited number of fungi (*Fusarium oxysporum*, *Phytophthora* and *Verticillium*) and only on root-knot nematodes (*Meloidogyne*). Cases exist where MeBr application does not solve phytopathological problems, since the effectiveness of MeBr depends on soil conditions such as pH, moisture, depth, content of organic matter, biological activity and temperature (Bello and Tello 1998). EU experts feel that if 40 % of the farmers used dose reduction methods and 50 % used alternatives, a 90 % reduction could be attained. All this demonstrates that MeBr can be rapidly eliminated in the EU, since alternatives are economically and technically viable in the majority of cases (Tierney 2000).

The major non-chemical alternatives are:

- solarization, which uses solar energy to control soil pathogens;
- biofumigation, which is based on the use of gases from the biodegradation of organic matter
- cultivation on substrates

- resistant varieties
- grafting in vegetables as well as in perennial plants
- steaming and
- biological control.

Among the outstanding chemical alternatives, whenever application is performed correctly, are found:

- mixtures of 1.3-D plus chloropicrin, dazomet and metam sodium.
- the use of virtually impermeable film (VIF), which permits reductions of up to 80 % of applied MeBr.

Outstanding are also ICM techniques, which consist in a combination of biological alternatives, cultivation practices and reduced doses of low-risk chemical products. However, it must be remembered that chemical products are an alternative solely to comply with the gradual reduction imposed to the Parties by Montreal Protocol, and in no way are they a solution for the future. They are only short term solutions as substitutes for MeBr to avoid the possible economic impact from the prohibition during the next few years (Bello *et al*. 1998; MBTOC 1998).

II. CONSUMPTION OF MeBr

The consumption of MeBr in Spain does not surpass 8,988 ha of treated crops, a negligible percentage in comparison to the total surface devoted to vegetable and fruit crops. Most of the vegetable areas treated with MeBr in Spain does not reach reach 1 % (Table 1), except for strawberries only in Huelva (33.1 %) and strawberry nurseries in Castilla-Leon, where MeBr is applied in most of the fields, and cut flowers in Cadiz (20 %). Among the Autonomous Spanish Communities, Andalusia (1,930 t), Valencia (877 t), Murcia (719 t), Castile-Leon (304 t) and Catalonia (130 t) stand out for their consumption. The consumption of the remaining communities is well below 100 t; and is zero in Aragon, Asturias, Cantabria, La Rioja and the Basque Provinces (Fig. 1; Table 1).

With regard to crops, strawberry is the most treated, with 33 % of its area (1,399 t), then pepper 29 % (1,206 t), vegetables in general 12 % (540 t), cut flowers 9 % (393 t), cucurbits 9 % (356 t), tomato 5 % (213 t) and others 3 % (134 t). Lately with the enforcement of regulations for integrated production in citrus and the use of float tray techniques in tobacco seedbeds, MeBr is practically not used for these crops (Table 1; Fig. 2). On the other hand, MeBr is a forbidden pesticide according to the majority of ICM's regulations, which represent over one million ha in our country.

III. BACKGROUND ON THE SEARCH FOR ALTERNATIVES TO MeBr IN SPAIN

Since 1992 an intensive work on the development of new alternatives to replace MeBr in Spain has been carried out. Its major results were summarized by Bolivar (1999), who pointed out that:

(1) a decrease in the dose of MeBr can be effective for complying with the 75 % reduction established by the EU for the year 2003;

(2) treatments with the mixture of 1.3-D plus chloropicrin give results similar to MeBr;
(3) biofumigation plus solarization gives good results when applied under appropriate conditions;
(4) there are still no alternatives in Spain for strawberry or cut flower nurseries; and
(5) that pepper crops present problems of soil deterioration.

IV. PRODUCTION OF TOMATO AND OTHER CROPS WITHOUT MeBr

The cultivation of tomato is a good example of a MeBr reduction in Spain, since only 875 ha are treated with this fumigant (Vares 1998), which represents 10 % of the area cultivated in controlled environments and only 1.5 % of the total area for this crop (60,155 ha; MAPA 1996). The low consumption of MeBr in tomatoes is noteworthy because this crop uses 5,271 t (37 %) being the number one in MeBr consumption in the European Union. The non-use of MeBr in tomatoes in Spain is due to the absence of several highly virulent pathogens. among them the strain 2 of *Fusarium oxysporum* f. sp. *lycopersici; Sclerotium rolfsii* (only found in industrial tomato in Estremadura); *Phytophthora* spp., which does not cause problems in Spain; *Pyrenochaeta lycopersici + Colletotrichum coccodes + Rhizoctonia solani* complex, which has been found only in the Basque Provinces; and the absence of highly pathogenic nematodes that affect crops in tropical countries (Tello 2000).

As alternatives to MeBr, Spain is using resistant varieties, artificial and natural substrates such as the sand-covered soils of the southern part of the peninsula and of the Canary Islands, grafting, biofumigation, crop rotation and fallow land, planning the time for sowing, preventative measures in seedbeds and chemical controls. Steam is not used because of the high cost of this technique. In summer solarization occurs naturally, as a phenomenon, but this technique, in general, is not widespread among farmers.

A biological control of tomato pathogens exists through other soil organisms since large populations of *Pasteuria penetrans* have been frequently observed parasitizing *Meloidogyne* spp. in tomato fields. Therefore, it is assumed that they have an important role in the regulation of the populations of these nematodes (Bello *et al*. 1997; Tello 2000).
MeBr consumption is low or non existing in grapes, in bananas in the Canary Islands, fruit trees and vegetables in the Ebro River Valley, tobacco in Estremadura, and citrus trees in general. The use of MeBr in these crops is of only 78 t (1.5 % of the total consumption) to treat 136 ha (0.05 %) (Bello and Tello 1998).

V. ALTERNATIVES TO MeBr

The Ministry of Agriculture, Fishing and Food (MAPA)'s regulations, which went into effect in June 1998, established a dose of 20 - 40 g m^{-2}, by which a reduction could be achieved of over 50 % of the consumption of MeBr in Spain. At the same time, this measure included the reduction of MeBr concentration in its formulations, by increasing chloropicrin from 2 % to 50 %, equal to more than 30 % reduction of the total MeBr then consumed. By this way a total reduction of 70 – 80 % was foreseen to be reached.

Strawberry producers in Huelva have been applying MeBr in strips and / or mixed with chloropicrin (67 % of MeBr + 33 % of chloropicrin), techniques which enable the growers to use rates of less than than 20 g / m^2 of MeBr. Other measures applied are the use of short-lasting crops for no more than one year and the use of low doses of chemical products combined with solarization. The strawberry sector contributes over 4 million days of wages a year to the economy of Huelva, without counting the wages created in the Castilla - Leon Autonomous Region's strawberry nurseries. The owners of the strawberry nurseries in Castilla - Leon have been applying successfully the mixture of MeBr + chlorpicrin as well as low doses of MeBr (350-650 kg ha^{-1}) (Bello and Tello 1998).

Pepper producers in Campo de Cartagena (Murcia) and in southern Alicante are using 300 kg ha^{-1} as the maximum dose of the 98 % MeBr + 2 % chloropicrin mixture. This rate is 50 % of the conventional dose used. The growers are also compelled to use MeBr under VIF plastic.

Pepper cultivation generates employment for 3,569 field workers, 1,785 warehouse personnel and 714 indirect jobs, which is a total of 6068 jobs equal to $ 46 million US in manual labor. Therefore the importance of peppers in this area is evident.

Biofumigation and the use of resistant grafts have also been studied as alternatives. Biofumigation was found to be as effective as MeBr whenever it is applied combined with soil solarization in the months of August and September. Some pepper root stocks effective against *Phytophtora* wer also selected (Lacasa *et al.* 2000).

The results obtained by the Project for problematic crops("Environmental-friendly, Economically-viable Alternatives to the Conventional Use of MeBr") coordinated by MAPA, within the National Plan for Research and Development, is an evidence that MeBr can be reduced to 80 % for strawberries by the year 2003. Chemical and non-chemical alternatives for carrots were developed (Lopez-Aranda 1999). Some sound alternatives validated in peppers in Murcia (Lacasa *et al.* 1999). Based on all this information, it is difficult to understand how the EU experts have shown that MeBr sales in Spain (5,157 t) are 39.6 % of the EU total.

In Spain, successful application of biofumigation have been obtained in strawberries in Andalusia and Valencia; peppers in Murcia and Castilla-La Mancha; cucurbits in Valencia, Castilla-La Mancha and Madrid; tomato in Valencia and the Canary Islands; brassicae, cut flowers, citrus and fruit trees in Valencia; banana in the Canary Islands; and vineyards in Castilla-La Mancha (Bello *el al.* 1997, Bello and Melo 1998, Bello and Miquel 1998 a, b, Bello *el al.* 1998, Cebolla *et al.* 1999, García *et al.* 1999, Bello *et al.* 2000). Biofumigation has also been recently applied to Swiss chard crops in Madrid and carrot crops in Andalusia and Alicante. The most utilized biofumigants have been goat, sheep and cow manure, and residues from rice, mushroom, olive, brassicae, and gardens (Fig. 3).

The cost of biofumigation is minimal since the differences from the application of organic matter, a frequent practice in any ICM system, are in the characteristics of the organic matter and its method of application. Its effectiveness in controlling nematodes, fungi, insects, bacteria, and weeds is nearly the same as with the use of conventional pesticides. Biofumigation may also regulate viral problems by controlling vector organisms (Bello *et al.* 2000).

Biofumigation is an easy technique for farmers and technicians to apply, since it differs from the application of organic matter only in the choice of the biofumigant and in the method of application. The biofumigant should be in the process of decomposition. The method of application should take into account the need to retain the gases from the biofumigant that are produced in the biodegradation of the organic matter for at least two weeks, since its effect in the majority of cases is not biocidal, but rather biostatic. Therefore, it is necessary to prolong its action on pathogens throughout the course of time. A marked herbicidal effect has also been verified. It has been demonstrated that any agroindustrial residue or its combinations whith a C / N ratio between 8 and 20 can have a high biofumigating effect, which can be easily identified by the farmer since it delivers the characteristic odor of ammonia. It should be kept in mind, however, that not only nitrogen derivatives have a biofumigating effect. Therefore, it is advisable to characterize the the agro-industrial residues before its application as biofumigants,.

During transportation and storage of these organic materials in the field, care must be taken not to lose the gases produced from biodegradation, by covering the piles of the biofumigant with plastic until the time of application. A dose of 50 t ha^{-1} is recommended, although when problems with nematodes or fungi are very serious, 100 t ha^{-1} should be applied, a dose that can be reduced by means of cultivation techniques such as application in furrows. The biofumigant should be distributed uniformly, so that focuses of pathogens will not appear that could create problems for the crop. Once the biofumigant is distributed, it should be incorporated immediately into the soil by means of a rototiller, leaving the surface of the soil smooth with the application of the rototiller's leveler. It is watered, if possible by sprinkling, until the soil is saturated, although watering can be done by flooding, or drip irrigation can be installed. It is then covered with plastic for at least two weeks to retain the gases produced from the biodegradation of the organic matter.

When soils are shallow (<30cm), the use of plastic is not necessary; gases can be retained by frequent watering, which maintains a thin crust of clay on the surface. Biofumigation is recommended to be carried out when the temperature is over 20 ºC, although temperature is not a limiting factor. Biofumigation can be combined with solarization, by keeping the plastic in place for a period of one month, although it has been observed that this decreases the biological diversity of the soil. The use of local resources as biofumigants is recommended, since the principal limiting factor in biofumigation is the cost of transporting the organic matter. Some problems may arise in the fertilization of the soil and in plant nutrition such as phytotoxicity and nitrogen deficiency, but they can all be solved with adequate fertilization.

It is recommended to alternate the use of agricultural residues with green manure, especially from brassicae, using 5-8 kg m^{-2} of green matter, although combinations of legumes and grass can be applied. In the case of the use of green manure cultivated in the same field, fast growing plants should be used to be incorporated at least 30 days after having been planted, to avoid the increase of pathogen populations. The cultivation of brassicae after biofumigation can serve as bio-indicators of possible phytotoxicity, since the germination of these seeds is sensitive to phytotoxic substances. At the same time they are very sensitive to phytoparasitic nematodes and permit the detection of areas in the crop where biofumigation is not effective, acting like trap plants, and like biofumigants when incorporated into the soil.

The cost of biofumigation can reach the same value as MeBr, especially when animal manure, or agricultural residues, have to be brought from great distances. Costs can be reduced when green manure is used, which does not usually exceed 300 US$ ha^{-1}. But since biofumigation is actually simply the application of an organic amendment, which is a normal practice in ICM systems, the cost could be considered as zero. Some difficulties could arise at the beginning of the implementation of biofumigation, but with time the farmer will become more familiar with the method and will choose the best mixtures of biofumigants and their rates.

Solarization is a method, which is not effective by itself, especially when dealing with the control of mobile organisms such as nematodes. Due to absorbed heat the nematodes move deeper in the soil, but are again brought up to the surface of the soil when ploughing begins. Solarization has been effective in soils having a high content of organic matter, when combined with biofumigation), or in shallow soils. Solarization combined with biofumigation should last two months if the air temperature are over 40ºC (Lacasa *et al.* 1999). However, 30 to 45 days are enough during July and August, when the temperature of the soil is above 50ºC. A loss in the bio-diversity of the soil has been observed after solarization. The effectiveness of the method increases when combined with low doses of commercial fumigants. This alternative has proved to be effective in strawberries in Huelva and carrots in Cadiz. Solarization combined with fumigants, such as metam sodium, at rates of 100 cc m^{-2}, is a common practice in Spain. The effectiveness of this treatment is comparable to those with MeBr.

Grafting, aims at controlling soil borne diseases, it consists of cultivating a sensitive plant on the root system of another one resistant to the disease to be controlled. It is used in vegetables for solanaceous plants (tomato, eggplant and pepper) and for cucurbits (melon, cucumber and watermelon). Grafting can compete with MeBr in production, reliability and price. This technique is found widely introduced in Almeria and Valencia to control vascular *Fusarium* wilt in watermelon (Bello 1998, Bello *et al.* 1998).

In Spain tobacco seedbeds can be planted without MeBr, by using the floating tray technique (Blanco 2000), which allows to obtain seedlings in an easy, safe way with uniform root balls, quality and low cost. Trays remain floating on water in a pool from sowing to transplanting. Pools can be located outdoors in plastic micro-tunnels protected by thermal blankets, or indoors, in greenhouses. The walls of the pool should be 15 cm high and constructed with bricks, cement blocks, metal sheets or wood. When floating, the trays should stick out 1 cm above the top edge of the walls. Therefore the depth of the water in the pool will be approximately 10 cm, since the trays are about 6 cm high. The inside of the pool should be covered with two black plastic sheets. The substrate is based on peat.

It is necessary to use quality water and soluble fertilizers, which should be uniformly distributed throughout the pool. An adequate fertilizer would be 20-10-20, which should not contain any urea. Nitrogen should be of nitric and ammoniac origin in equal parts. It is recommended to add 80 to 100 ppm of nitrogen when filling the pool with water, or one week after sowing. Four weeks later, more water with 80 to 100 ppm of nitrogen is again added. An excess of nitrogen can make the plants more sensitive to disease.

Expanded high density (32 - 35 g / 1) polystyrene trays are used. A tray that gives us good results measures 61.5 x 34 x 6 cm and consists of 264 cells. Each cell should be in the form of an inverted pyramid or cone. The volume of each cell should range between 16 – 23 cm^3. In our trays cells have a volume of 17 cm^3. Cells are uniformly filled with substrate and seeds are sown in the center of the cell. Seeds must be pelletized, uniform in size and with a germinating power of over 90 %. During germination an optimum temperature of 21 - 24ºC is required. Preventive measures are indispensable to maintain the tobacco plants free from pests and diseases and so it is recommended to disinfect the various elements used with a solution of water plus 10 % commercial bleach. This technique has been used since 1991 in tobacco crops in Caceres (Estremadura), and is an effective alternative to MeBr.

Chemical alternatives. The 1.3-D plus chloropicrin (35 %) at a dose of 40 cm^3 / m^2 is just as effective an alternative as MeBr for strawberry crops, as well as for pepper and other vegetables in Spain. But it deals with only a temporary solution to the MeBr problem, since due to its carcinogenic effects and groundwater contamination, it is forbidden in various countries. The only recommendable chemical alternatives are limited to the application of dazomet (50 g / m^2) and low doses of metam sodium (60 - 100 cm^3/m^2) in combination with solarization, which has proven effective as an alternative to MeBr for strawberry in Huelva and carrot in Cadiz (Lopez-Aranda 1999). In Spain metam sodium is generally applied in doses between 1000-1200 l / ha, but the lowest dose approved by the Ministry of Agriculture is 600 l / ha (Bello *et al.* 1998).

Integrated Crop Management (ICM) is being applied in Spain to most of the crops that are treated with MeBr, especially tomato and other vegetables, banana, citrus fruits, vineyards and fruit trees.

The ICM system is effective in regulating pathogen populations and increasing crop production. Vegetable crops of short cycle (2-3 months) may be used as trap plants in winter.

The health and quality of seeds and plants are important elements in ICM. Sowing time is established by taking into account temperature changes unfavorables to pathogen development. For example, in the Canary Islands the planting time is stratified, it begins with highlands at the end of summer and ends on the coast by the end of autumn.

Resistant plants can also be used, the resistance should be managed appropriately, in order to avoid the incidence of more virulent pathogen populations. Resistance should be applied through grafting, not only in fruit trees, but also in vegetables, as root stocks, when varieties sensitive to pathogens need to be cultivated.

VI. DISCUSSION

Various companies and research teams in Spain have given special attention to the development of new alternatives to MeBr. The results obtained have been internationally recognized. Spain is one of the countries in the world that is decreasing its consumption of MeBr in tomato, fruit trees, vineyards, banana and tobacco. The biofumigation, solarization, grafting, floating trays for tobacco seedbeds, biological control and ICM are sound alternatives for the replacement of MeBr, whihc can also be adapted in other countries.

In Spain, the only crop considered as “critical" using MeBr is strawberry nurseries. The use of MeBr in this crop is due mainly to the commercial requirement of treating these plants with the fumigant.

MeBr consumption in Spain is relatively rational in the doses used as well as in the frequency of applications. In the majority of cases it is applied every two years, with treatments being localized in very specific areas and crops. MAPA’s regulations have brought a 50 % reduction in MeBr rates, which is also an economic achievement.

Among the chemical alternatives the cost of 1.3-D plus chloropicrin has not yet been established, but it is considered to be less than MeBr's one However, the application of this mixture has a high carcinogenic effect and may contaminate underground water. Therefore its application should be made in a rational manner, under the advice of specialized technicians. The remaining pesticides selected can be applied at a low dose when combined with solarization, the cost being much lower than MeBr. Specialized technicians are not needed for these applications. Biofumigation always results more economic than MeBr when local raw materials are used. It also increases crop production by 60 % (Bello *et al*. 2000).

The ICM system has used various methods, such as biofumigation with solarization in the months of July-September, the rotation of short cycle crops that act as trap plants and biofumigants, resistant varieties with grafts, and as a last resort crops grown on substrates (Bello *et al*. 1998). These alternatives in the majority of cases do not generally imply additional costs. Although highly qualified farmers and technicians are necessary to select the adequate alternative for each case, which will make the crop profitable and not be over-whelming to health and the environment, and to apply, when necessary, low doses of pesticides with limited environmental risks.

VII. CONCLUSIONS

1. MeBr for soil fumigation in Spain is mainly applied in strawberries (33 %), pepper (29 %), vegetables in general (12 %), cut flower (9 %), tomatoes (5 %) and other crops (3 %). Regions with the highest consumption are Andalusia, Murcia, Valencia, Castile - Leon and Catalonia. MeBr is not used in the majority of the autonomous regions, particularly in tomatoes, which is the major world consumer of MeBr. Effective alternatives have been developed for tobacco in Estremadura, which may be used in other countries still using MeBr.

2. There are alternatives for most of the crops where MeBr is used. Their implementation depends on the species of pathogen to be controlled, the crop and the geographical region. Viable alternative methods do not necessarily have the same effectiveness as MeBr, but they are also effective from the technical and economically point of view. In the short term, chemical alternatives will provide enough control of major pests. However, in the future the non-chemical alternatives will be more sustainable. Although some small economic differences may exist, the alternatives will be viable in the long term.

3. Among the alternatives to the use of MeBr, in first place is the dose reduction established by the "Ministry of Agriculture, Fishing and Food" at a dose of 20 - 40 g / m^2, according to whether VIP plastic is used, or not. At the same time formulations with a high percentage of chloropicrin (35 – 50 %) are recommended, and treatments with 1.3-D plus chloropicrin, low doses of metam sodium and other pesticides in combination with solarization. Among the non-chemical alternatives, biofumigation is exceptionally convenient, and it can be combined with solarization—both, whenever possible, within an ICM system which harmonizes cultural practices, crop rotation, grafting and resistant varieties.

4. Producers should become aware of the proximity of the ban on MeBr (year 2005). They should make all possible efforts to find alternatives for the control of soilborne pathogens that affect their crops and above all, should not plan any production system depending on MeBr since now on. Alternatives should continue to maintain the quality and profitability of agricultural production, without producing a negative impact on the health of living beings or on the environment. But most importantly, they should avoid proposals far from our agricultural and social reality.

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Table 1. Crops and MeBr consumption in Spain (for the year 1995) [1]

Crop[2]	Province	MeBr (t)	MeBr (ha)	% of Total ha[3]
1. Potato	1. Valencia [4]	**328** [5]	**602**	0.3
2. Tomato[6]	2. Alicante [4]	**110**	**194**	0.3
"	3. Almería [4]	**102** [5]	**205**	0.3
"	4. Murcia [4]	**26**	**52**	0.1
3. Beans	5. Almería [4]	rotated with tomato	(205)	0.8
4. Watermelon	6. Almería [4]	**173** [5]	**306**	1.4
"	7. Valencia [4]	rotated with potato	(602)	2.7
5. Zucchini	8. Almería [4]	rotated with watermelon	(306)	5.9
6. Melon	9. Almería [4]	rotated with watermelon	(306)	0.7
7. Cucumber	10. Almería [4]	rotated with watermelon	(306)	5.2
8. Carrot	11. Cádiz [4]	**21**	**50**	0.8
9. Vegetables in general	12. Cádiz	**122**	**250**	0.6
"	13. Valencia [4]	**75**	**140**	0.03
"	14. Barcelona [4]	**39**	**62**	0.02
10. Cut flowers	15. Cádiz [4]	**321**	**495**	20.0
"	16. Barcelona [4]	**39**	**54**	2.2
"	17. Sevilla [4]	**31**	**54**	2.2
11. Pepper	21. Murcia	**668**	**1,271**	5.2
"	22. Alicante	**305**	**560**	2.3
"	23. Almería [4]	**203**	**360**	1.5
12. Strawberry	18. Huelva [4]	**897**	**2,919**	33.1
"	19. Barcelona [4]	**52**	**107**	1.2
"	20. Majorca	**15**	**19**	0.2
13.Strawberry nurseries	24. Segovia	**157**	**301**	30.7
"	25. Ávila	**101**	**282**	28.7
"	26. Navarre	**90**	**153**	15.6
"	27. Palencia	**33**	**129**	13.2
"	28. Huelva	**27**	**78**	7.9
"	29. Valladolid	**15**	**38**	3.9
- Citrus fruits, MeBr is forbidden in ICM		**78**	**136**	**0.1**
- The Canary Isalnds crop is not specified		**79**	**?**	
- Others (consumption < 15 t)		**84**	**171**	
	Total	**4,191**	**8,988**	

[1] The percentage of chloropicrin is deducted, although consumption could have diminished by more than 50 % due to the MAPA regulations of 1998.
[2] Crops are given in the order of lesser to greater difficulty to eliminate MeBr.
[3] According to MAPA (1996).
[4] Methyl bromide is used biannually.
[5] Forms part of a crop rotation system.
[6] Methyl bromide is practically not used for tomato in Spain.

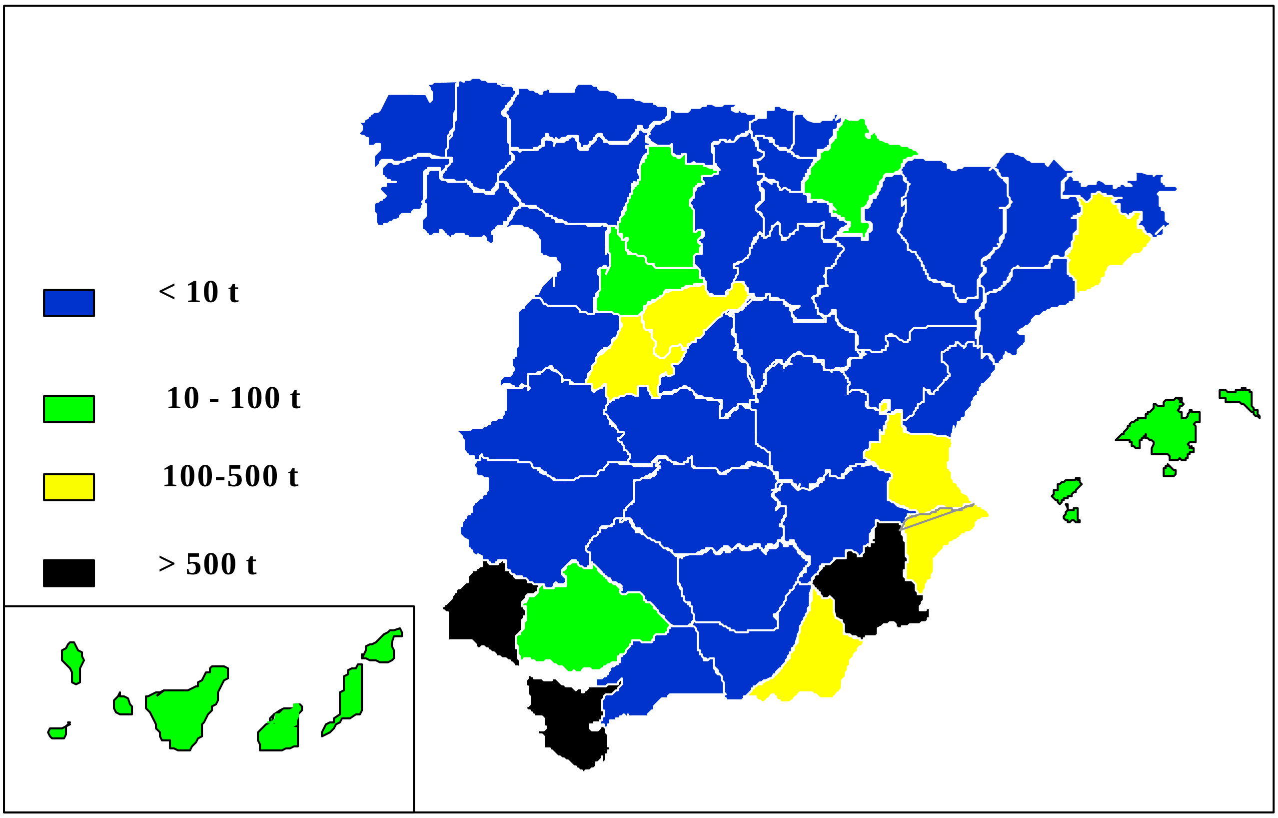

Fig. 1. Distribution of methyl bromide consumption in Spain (Canary Islands inset).

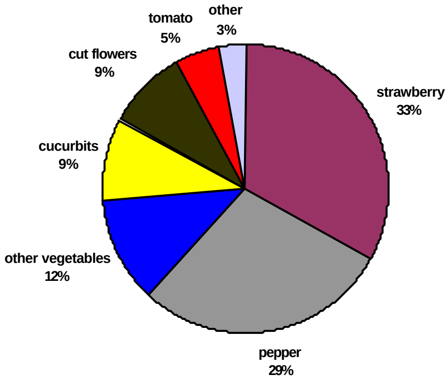

Fig. 2. Consumption of methyl bromide by crop in Spain.

AVAILABLE ALTERNATIVES FOR ITALY

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Summary. The use of methly bromide in Italy is extremely high, ranking second in the world. This is especially due to the importance of the Italian horticultural sector, which is characterized by intensive cultivation of high value crops without rotation. Alternatives to the use of MeBr for soil fumigation are being increasingly used and others are being developed, in order to meet the deadlines for MeBr phase-out. Especially the use of steam, soil solarization, chemical alternatives and their combinations, as well as combinations of cultural practices, physical methods and chemicals, provide effective control of soil pests.

Key words: intensive cultivation, fungi, methyl bromide, steam, chemical alternatives

I. INTRODUCTION

Italian horticulture is characterized by intensive cultivation systems, highly specialized and usually of small size, where the high plant density and the repeated planting of the same crop, practice very common in the case of valuable crops, cause a build-up of detrimental biological factors in the soil. The aggressiveness and rate of accumulation of different pathogens in the soil depends upon factors such as host susceptibility to pathogens, cropping history, physical and biological properties of the soil, cultural practices, climate, control measures and field hygiene.

Soil disinfestation is usually carried out in the case of protected vegetable and ornamental crops of high value and sometimes also in the open field (Katan, 1984; Garibaldi and Gullino, 1995; Gullino and Garibaldi, 1995). The main goal of soil disinfestation is to eliminate, or simply control, major soilborne plant pathogens and pests, usually before planting. In particularl in the Italian vegetable and ornamental sectors, fungi represent the most important pathogens to be controlled. A non-comprehensive list of the major fungal pathogens of vegetable and ornamental crops in Italy is presented in Table 1.

From a technical point of view, soil disinfestation should be economically feasible. Under these perspectives, fumigants are often the method of choice, due to their relative low cost and broad spectrum of activity. Certain physical and chemical characteristics of MeBr amde this fumigant the most widely used in Italy against soilborne pathogens. MeBr has a broad spectrum of activity, quick and deep penetration into the soil; very short exposure period; fast dissipation from the soil after fumigation; penetration into undecomposed material; increased Growth Response effect; good efficacy in a wide range of temperatures; efficacy with more than one

Table 1. Main fungal pathogens of vegetable and ornamental crops in Italy

PATHOGEN	HOST PLANT
Fusarium oxysporum f. sp. *melonis*	MELON
Fusarium oxysporum f. sp. *cucumerinum*	CUCUMBER
Fusarium oxysporum f. sp *basilici*	BASIL
Fusarium oxysporum f. sp *niveum*	WATERMELON
Fusarium oxysporum f. sp. *cyclaminis*	CYCLAMEN
Fusarium oxysporum f. sp. *dianthi*	CARNATION
Fusarium oxysporum f. sp. *lycopersici*	TOMATOES
Fusarium solani f. sp. *Cucurbitae*	CUCURBITS
Fusarium solani f. sp. *Phaseoli*	BEANS
Fusarium tabacinum	BASIL
Phytophthora capsici	PEPPERS, TOMATOES, EGGPLANTS AND CUCURBITS
Phytophthora cactorum	STRAWBERRIES
Phytophthora cryptogea	GERBERA
Phytophthora fragariae	STRAWBERRIES
Phytophthora parasitica	CARNATIONS, TOMATOES AND OTHER SPECIES
Pyrenochaeta lycopersici	TOMATOES
Pythium ultimum	DIFFERENT SPECIES IN SEEDBEDS
Rhizoctonia solani	LETTUCE, BEANS, BASIL CARNATIONS, ARTICHOKES AND OTHER PLANTS IN SEEDBEDS
Sclerotinia sclerotiorum	LETTUCE, CUCURBITS BASIL ARTICHOKES, BEANS AND OTHER PLANTS IN SEEDBEDS
Thielaviopsis basicola	SEVERAL VEGETABLE AND ORNAMENTAL SPECIES
Verticillium dahliae	TOMATOES, EGGPLANTS, STRAWBERRIES, CUCURBITS, ARTICHOKES, ROSE AND GERBERA

crop. Italy ranks second in the world, together with Japan, and first in Europe for consumption of MeBr, due to the importance of its horticultural sector (Gullino and Clini, 1998).

Recently, the restrictions on the use of MeBr because of ozone depletion, have set an interesting scientific, technical and political debate. A high degree of cooperation between the scientific, technical and political sectors is required, if viable solutions are to be in place for many uses, by the time MeBr is withdrawn (Gullino and Clini, 1999). No single "plug-in" replacement for MeBr appears to exist. At present, it is possible to distinguish two main categories of alternatives:

- alternatives that have replaced the use of MeBr in some areas;
- alternatives that are effective for the control of one or more pest organisms (insects, nematodes, pathogens, or weeds) currently controlled by MeBr in a particular crop but without achieving widespread use.

II. ALTERNATIVES CURRENTLY USED IN ITALY

In this section, the technologies alternative to the use of MeBr for soil disinfestation currently used in Italy are briefly described, with special emphasis on their positive features and constraints encountered in their implementation under the Italian cultural and environmental conditions.

1. NON-CHEMICAL ALTERNATIVES

Cultural practices

In the development of new alternatives to replace MeBr, the natural approach is to check the latest technological advances and investigate the ways to implement these new systems or control practices. There is also some merit, however, in looking back and reviewing the situation which existed before MeBr was introduced (Matta, 1988). Crop rotation is one of the best examples, as it confirms to be extremely helpful in controlling the spread of many soil-borne pathogens (Palti, 1981). A significant commitment to applied research and technology transfer programmes will still be necessary to take full advantage of the potential of cultural practices in the many different agricultural situations.

Resistant varieties

Varieties, which are resistant, or tolerant to one, or few, specific pathogens (and races) are already available for many crops. Resistant hybrids with multiple resistance to several pathogens exist and are currently used in vegetable production (Cirulli, 1988; Laterrot, 1991). In most cases new varieties are developed through plant breeding techniques to address specific pest problems, but systematic genetic modification of germplasm by using new biotechnologies is becoming more frequent.

Positive features

- simple application;
- easily combinable with other control methods;
- low environmental impact.

Constraints

- use limited by time and resources, both genetic and financial, required for developing multiple-resistant varieties with appropriate commercially acceptable quality and yields;
- difficulty in developing multi-resistant varieties;
- resistant genes may be unstable in unfavorable environmental conditions, e.g. high soil temperatures, high salinity, or in presence of “new races” of pathogens and may limit the efficacy of resistant plants;
- few resistant varieties available for ornamental crops;
- limited spectrum of activity;
- higher production costs for F_1 hybrids.

Soilless cultivation

Soilless cultivation is rapidly expanding also in Italy, although slowly in comparison with Northern Europe. This technique may bridge unusual production periods and circumstances, and may also serve as an answer to the need of reducing the use of soil fumigants. Soilless cultivation represents an interesting alternative to the traditional agricultural systems for high value crops such as rose, carnation, gerbera, basil, lettuce, etc. (Serra, 1994; Tognoni and Serra, 1994). The phytopathological problems of soilless cultivation systems have been recently reviewed (Gullino and Garibaldi, 1994; Stanghellini and Rasmussen, 1994). The choice of the most suitable soilless cultivation system for a given environment relies on technical, economical and phytopathological factors.

Soilless cultivation is increasingly adopted in Italy in the case of ornamental crops (rose, gerbera) and, in very limited situations, in northern Italy for strawberry. A total of approximately 100 ha is at present cultivated soilless in Italy. It must be noted that all the soilless systems adopted in Italy are open, thus without recirculation of the nutrient solution.

Positive features

- higher productivity and quality;
- broadly available, efficient, performs consistently and increases yields;
- avoids, rather than to control, soilborne pathogens;
- better control of crop nutrients and phytosanitary conditions;
- recovery of marginal areas;
- prevents soil sickness;
- easier cultural practices;
- lower discharge of nutrients and water in the environment, resulting in reduced consumption and environmental impact (in closed circuit systems).

Constraints

- higher initial investments;
- costs and problems related to the disinfestation, recycling and disposal of recirculated solution and substrates;
- availability of varieties adapted to the special hydroponic environment;
- high environmental impact (in open circuit systems);
- risks of root asphyxia, excessive salinity, or epidemics in case of mismanagement;
- possible establishment of new diseases.

Crop rotation

It is particularly difficult to apply crop rotation in intensive vegetable and ornamental crop systems and for this reason it is not common in Italy as an alternative to MeBr.

In practice, in Italy, the following rotations can be used:

a) under greenhouse conditions:

- tomato (or other solanaceous crops) and lettuce;
- tomato and cucurbits;
- cucurbits, lettuce, solanaceous crops;

b) in the field:

- strawberry, *Brassicaceae*, cereals.

Positive features

- reduction of pathogen and pest inoculum, and improvement of physical, chemical and biological properties of the soil.

Constraints

- in case of intensive cultivation, it is not possible to make crop rotation long enough to reduce soil pathogen and pest populations;
- ineffectiveness against several polyphagous *(Verticillium* spp. and *Rhizoctonia solani*) or long-lived pathogens (chlamydospores of *Fusarium* spp., microsclerotia of *Verticillium* spp. or oospores of *Phytophthora*) or some saprophytes on organic debris, in competition with the soil flora and fauna (*Pythium* spp., *Rhizoctonia solani* and *Sclerotium* spp.);
- need of additional land to achieve the same production as at presently achieved with MeBr;

limited availability of alternative crops suitable not only as a non-host crop but also from an economic point of view.

Physical methods

There are two different physical approaches to soil disinfestation: steaming and soil solarization. (Katan, 1984; Gullino and Garibaldi, 1995).

Steam

In Italy, steam is almost exclusively applied in the case of high value greenhouse crops (Gullino and Garibaldi, 1995). However, new application technologies are under development, which might significantly reduce the costs of such method. At present it is adopted only in the case of ornamental crops (rose, gerbera), or for high value vegetables (i.e. basil), due to its high cost. In Italy, steaming is carried out by adopting the most traditional technique of sheet steaming. Sheets are smoothed out over the soil and enclosed at the edges; steam is then blown under the sheets and left to penetrate the soil.

Positive features

- broad spectrum of activity;
- no soil contamination;
- no waiting period before planting.

Constraints

- low selectivity: "biological vacuum" and consequent pathogen recolonization ("boomerang effect"[1]);
- release of heavy metals: phytotoxicity for the accumulation of manganese, particularly in acid soils;
- swift decomposition of organic matter and consequently accumulation of ammonia, carbon dioxide and several other phytotoxic compounds;
- solubilization of inorganic compounds;
- modification of the solubility and availability of the nutrient elements;
- feasible only on small surfaces (benches, seedbeds, soilless cultivation, etc.);
- high initial investments and high energy-consuming technique;
- contribution to the global warming process due to the use of fossil fuel.

Soil solarization

Southern Italy provides excellent conditions for implementation of soil solarization (Cartia, 1989). However, despite the fact that incentives to the implementation of soil solarization have been attempted in the past (i.e. free plastic for soil mulching in the Liguria Region; plastic recycling in Sicily), soil solarization is rarely adopted in practice in Italy. At present a maximum of 50 ha are solarized, especially in southern Italy (Campania and Sicily Regions). Bench solarization and solarization in greenhouses are new applications of this technique that may help its spreading even in marginal climatic areas (i.e. North-Central Italy) and seasons (Garibaldi and Gullino, 1991).

Positive features

- no harmful residue effects;
- low environmental impact;
- long-term effects on disease control;
- IGR (Increased Growth Response): increases crop yield and quality due to chemical and biological mechanisms;
- relatively low cost;
- no "biological vacuum" and consequently no "boomerang effect". Solarization is a sort of soil pasteurization which preserves the beneficial soil flora and fauna;
- improvement in water conservation in the soil and modification of soil temperatures when mulch is maintained as a row cover during the following crop;
- successfully used for disinfestation of artificial growth substrates and materials;
- reduced mulching period and applicable in colder climates, if combined with other pest control methods.

Constraints

- land out of production for at least 1 month during the hottest part of the year: problems in the colder growing areas for certain summer crops;
- for successful treatment a good level biological knowledge is required;

[1] Several soil disinfestation techniques (fumigants, steam, etc.) reduce not only the pathogens, but also the beneficial fauna and flora naturally present in the soil ("biological vacuum"). In such conditions, soil can be easily re-colonized by all kind of pathogens, even those usually considered of minor importance ("boomerang effect"). Re-infestation takes place through the irrigation water, infected soil particles, or crop debris, etc.

- climate and meteorological unpredictability;
- restriction to certain climatic areas and seasons;
- material and labor intensive practice;
- disposal and recycling of large amounts of PE films problems and additional costs;
- large amount of irrigation water required to increase soil thermal conductivity and capacity (especially for sandy soils), and to increase susceptibility of pathogens;
- limited spectrum of activity (slight nematocide effect) compared to MeBr and steam.

2. CHEMICAL ALTERNATIVES

Methyl isothiocyanate (MITC) and its generators

Metam sodium is a liquid soil chemical, effective for controlling arthropods, some weeds and soilborne pathogens, principally fungi, and a limited number of parasitic nematode species. It is applied to the soil by direct injection, or through the irrigation system. Metam sodium must be applied when soil temperatures are between 15 and 30°C. The application rate is 100 ml / m^2 (with formulations at 32,7 % of a.i.). At high inoculum concentrations, low soil temperatures, or for heavy soils it is necessary to increase the rate up to 800 ml / m^2.

Dazomet is a granular pre-planting soil chemical and has been reported to control weeds, nematodes and fungi. It requires mechanical distribution in the soil for good movement and efficacy. During the treatment the soil should be covered with plastic sheets. The application rate is 80-100 g / m^2 (with formulations at 99 % of p.a.).

Positive features

- relatively low cost;
- slightly bactericidal.

Constraints

- limited spectrum of activity (low efficacy against several vascular diseases and some specific soilborne pathogens such as *Pyrenochaeta lycopersici*);
- usually not effective in the presence of high pathogen pressure;
- inconsistent control due to non-uniform distribution in the soil;
- climate and meteorological unpredictability;
- long waiting period between treatment and planting (approximately 30 days);
- high environmental impact;
- problems with consistency of yield;
- "biological vacuum" and consequent "boomerang effect";
- undesirable effects against the natural beneficial soil population of the (several mycorrhizae, *Trichoderma* spp., *Penicillium*, etc.);
- disposal and recycling of large amounts of PE films problems and additional costs.

1,3 dichloropropene (1,3-D)

Liquid 1,3-D, applied to the soil by injection, provides effective control of nematodes, insects, some weeds and some pathogenic fungi. During treatment the soil remains covered with plastic mulches.

1,3-D is usually applied in combination with other chemicals such as chloropicrin, metam sodium, etc. Application rate is 12-20 ml / m^2 (with formulations at 97 % of p.a.); higher rate are applied to heavy soils.

Positive features

- good nematocide effect;
- slight IGR effect;
- relatively low cost.

Constraints

- limited spectrum of activity: nematocide with some insecticide, herbicide and fungicide effects;
- accelerated degradation of 1,3-D by soil micro-organisms after repeated applications, resulting in variable yield;
- inconsistent control due to non-uniform distribution in the soil;
- long waiting period between treatment and planting (approximately 28 days);
- additional restriction limiting its application rate, geographical areas of use, as well as imposing costly requirements for personal worker safety equipment in the field;
- high environmental impact: 1,3-D residues has been reported in air and shallow groundwater;
- forbidden in greenhouse and closed space;
- if mixed with metam sodium it releases a strong odor.

<u>Chloropicrin</u>

It is worth mentioning Chloropicrin, although still forbidden in Italy (because still registered as a war gas), since it is also a valid option. Presently under registration in Italy, it controls most soilborne fungi, root destroying insects and other organisms such as slugs, snails and earwigs.

III. DISCUSSION

Since new fumigants with a broad spectrum of activity and of low environmental impact have not been developed, yet, growers are forced to use old compounds. In Italy, recent data made available by Agrofarma, showed an increase in fumigant usage in 1998 of 11 % in value and 16 % in quantity (Anonymous, 1999).

Combinations of chemical and non-chemical alternatives, notably soil solarization, led to encouraging results: examples include metam sodium, dazomet, or 1,3-D + chloropicrin in combination with solarization, or gas impermeable plastic mulches. Studies are being conducted to evaluate additional combinations and to optimize ratios of chemicals and improved methods of application.

Particularly interesting appears the possibility of applying fumigants such as metam-sodium and dazomet under plastic. Covering the soil with low-density polyethylene film (LPDE) allowed to use a half dose of the fumigants, with generally good results, both under greenhouse and field conditions. Moreover, such practices reduced the emission of unpleasant smells, particularly in the vicinity of houses (Gullino *et al*., 1998: Minuto *et al*, 2000).

Also the combination of two weeks of soil solarization with half dose of fumigants proved to be effective in most cases and allowed a shortening of solarization, permitting a reduction in the non cultivation period. Such a combination was effective on subsequent crops, thus confirming the long term effect described for soil solarization (Katan and DeVay, 1991). The possibility of combining soil solarization with reduced dosages of fumigants could indeed increase the number of growers using solarization as a disinfestation method, helping to reduce the present dependance on chemicals. It must be stressed that the usage of half dose of fumigant in combination with a shorter period of solarization remains essential, at present, in order to achieve an acceptable level of disesase control, especially in the case of high value protected crops (Gullino, 1998). In Table 2, alternative technologies in Italy are summarized, presenting them on a feasibility and applicability degree basis.

IV. CONCLUSIONS

The efficacy, availability of simple application systems and technology, together with the broad spectrum of activity and relatively low cost, make MeBr extremely difficult to replace. Furthermore, many of the options are not yet at a stage where they could be used extensively without considerable increase of costs.

The appropriateness of a given alternative, or combination of alternatives, is dependent on a variety of factors, including social infrastructures, climate, market, presence of pathogens, land availability, soil type and conditions. The complex interactions among these factors require the choice of the best alternatives on a case-by-case basis. Nevertheless, there are some practices which have widespread applicability, though not necessarily producing the same yield and having the same profitability as MeBr, and which may need local optimization to perform to their full potential. For instance, alternatives that have been developed in cold climate and then transferred to warmer regions, or vice-versa.

Furthermore, to successfully replace MeBr use, many of the alternative processes identified must be used in combinations. For soil treatment, there is wide agreement that IPM systems are needed to replace MeBr-based strategies, since no single alternative is currently, or likely to become, available. Site-specific IPM treatment programmes combine two, or more, methods selected among biological, cultural, physical, mechanical and chemical methods (Albajes *et al*., 1999). Some alternatives have a limited spectrum of activity, thus some combinations and / or rotations with different alternatives may achieve broad spectrum pest control and yields approaching, or exceeding, those obtained with MeBr.

On a longer range, since the few available chemical alternatives to MeBr (i.e. metam sodium and dazomet) will be widely applied, their safe application is essential to obtain a satisfactory level of disease control, without causing negative environmental side-effects. In this perspective, it is crucial to exploit to the utmost the few available fumigants and to use application technologies which permit their dosages to be reduced while retaining their activity.

The higher costs and the fear of loss of reliability represent among the growers the major limits to the wide-spread of the most promising alternatives to the use of MeBr already available. Moreover, many countries cannot depend on an efficient extension service web which helps growers to switch from MeBr to other new techniques.

From the results of a survey carried out by Di.Va.P.R.A. (Dipartimento di Valorizzazione e Protezione delle Risorse Agroforestali, Turin University, Italy) with

Table 2. Technical evaluation of the degree of development, the transferability into practice and the efficacy of alternative technologies to the use of MeBr as soil fumigant

TREATMENTS	DEGREE OF DEVELOPMENT[1]	TRANSFERABILITY INTO PRACTICE[2]	EFFICACY: SPECTRUM OF ACTIVITY		EFFICACY: CLIMATIC DEPENDENCE	
			SPECIFIC	BROAD	LOW	HIGH
	4	**100**		✓	✓	
NON-CHEMICAL METHODS						
Agricultural practices						
Crop rotation	4	75		✓	✓	
Resistant varieties	4	75	✓		✓	
Grafting	2	60		✓	✓	
Soil amendments and biofumigation	2	60	✓		✓	
Soilless cultivation systems	2-3	60		✓	✓	
Physical control						
Steam	4	100		✓	✓	
Soil solarization	3	75		✓		✓
Biological control	2	50	✓			✓
CHEMICAL METHODS						
Metam sodium	4	90		✓		✓
Dazomet	4	90		✓		✓
1,3-D	4	90	✓			✓
Chloropicrin [3]	1	50	✓		✓	

[1] 1 = at experimental stage in the laboratory; 2 = at experimental stage in the field; 3 = at small scale; 4 = at commercial scale.
[2] Feasibility: from 0 to 100: 0 = degree of feasibility in the Italian agricultural reality (100 = extremely high feasibility).
[3] Under registration in Italy.

the help of technicians belonging to the "Servizi Fitosanitari" and the Growers Associations (Gullino *et al*., 1998), the lack of know-how and information appears as the main reason for growers' lack of confidence.

A strong action is needed, in order to make sure that alternatives to MeBr will be applied with a long term perspective, based on a sustainable view of agriculture. Extension service people and other operators of the sector are thus called to provide the adequate support to growers in order to help them to switch from MeBr to other alternative methods. The fragmentary and diversified reality of the Italian agriculture makes this task even more difficult.

In conclusion, the diffusion of the scientific results plays an essential role in the process of transfer into practice of the new techniques of soil disinfestation. Only a global, coordinate approach, involving all actors (growers, researchers, fumigators, technicians, etc.) will allow to switch smoothly from MeBr to its alternatives.

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CHAPTER IV: ASIA

APPROACHES FOR THE REDUCTION OF THE USE OF METHYL BROMIDE AND ALTERNATIVES IN JAPAN

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Summary. In Japan, each prefecture has its own programme to develop and disseminate alternatives to methyl bromide, especially for vegetables, for the phase-out of this fumigant in 2005. These programmes, which vary depending on the crop, are based on pre-planting treatments. Due to the efforts of the stakeholders concerned, MeBr for soil fumigation is being gradually replaced by alternatives and the use of MeBr is decreasing. Physical, chemical and biological alternatives proved to be effective in controlling soilborne pests. In order to achieve a broad range control of the various pests, combinations of different methods are used.

Key Words: methyl bromide, physical alternatives, hot water, orugaloi film, rotations, resistance, biological control, fumigants, contact pesticides

I. INTRODUCTION

In Japan MeBr is mainly used for soil and quarantine treatments. Compared with other pesticides, the fumigation with MeBr is faster and leads to better results even under low temperatures.

The Japanese time frame for the period 1995 - 2000 to control the production of MeBr was as follows:

1. Freeze of production at the base level of 1991 in 1995
2. Five percent reduction in 1996
3. Ten percent reduction in 1997
4. Fifteen percent reduction in 1998
5. Twenty-five percent reduction in 1999
6. Thirty percent reduction in 2000

To date Japan has reduced MeBr production in advance of the control deadlines established by Montreal Protocol. Starting July 6, 1993, a campaign for the reduction of emission of MeBr was conducted by the government and the farmers were encouraged to use alternative methods to this fumigant. The Ministry of Agriculture, Forests and Fisheries (MAFF) issued a special notice to the farmers, providing guidance on the use and reduction of emission of MeBr. In case the use of MeBr was absolutely necessary, it was strongly recommended to cover the soil surface with polyethylene film or vinyl film sheet. This practice is suggested particularly for greenhouses.

In order to control the production and use of MeBr in Japan, manufacturers and / or importers are required to obtain permission from the Ozone Protection Office of the Ministry of International Trade and Industry (MITI) to synthesize and / or import MeBr. After review of the application, MITI gives a permission to synthesize and / or import under the production limit of Montreal Protocol. After that year has passed, they have to report the record of actual amount of synthesis, import, export and remaining quantity in stocks of MeBr for that year to MITI. Therefore, MITI obtains detailed information about the production and consumption of MeBr during each year. All this information is then provided to MAFF by MITI. Therefore, MAFF has full information on the amount of production, import, export, shipment for domestic use, and use for quarantine pests. According to the Article 7 of Montreal Protocol, every country is required to report to UNEP the volume of production, import and export of MeBr.

In Japan, each prefecture has its own programme for the development of the alternatives for MeBr phase-out. This programme is mainly based on the crops and soilborne pests present, and the need to control those pests by soil fumigation as pre-planting treatments, which vary from crop to crop.

II. CURRENT SITUATION OF METHYL BROMIDE USE IN JAPAN FOR SOIL TREATMENT

In 1999 the use of MeBr for soil treatment in Japan still amounted to 4,391 tons (Table 1), which means an extensive use by farmers. This fumigant is favourably used in pre-planting treatments in crops such as pepper, melon, watermelon, strawberry, cucumber and cut flower for the control of insects, nematodes, weeds and soil born pathogens

Table 1. Sales and volume of MeBr used in Japan (tons) *

Use	1991	1992	1993	1994	1995	1996	1997	1998	1999
Soil	6269	6594	7241	7782	5742	5559	5470	5336	4391
Quarantine	2848	2646	2712	2703	2448	2198	2030	1679	1876
Others	219	121	204	426	523	431	408	269	517
Total	9336	9361	10157	10911	8713	8188	7908	7284	6784

* Source: MAFF Plant Protection Division

such as viruses, bacteria, and fungi. In protected areas, such as greenhouses, it is absolutely necessary of the use of soil treatments. A remarkable advantage of MeBr is that it is effective against all sorts of soilborne pests, including plant viruses, with short treatments even under low temperatures during the winter. For disinfecting the soil in nursery beds and for transplanting, many farmers apply MeBr twice a year. For all these reasons it is still popular among the farmers. However, the supply of MeBr in Japan has been decreasing and prices increasing and it will be phased-out in 2005. The farmers realized this trend and they are trying to apply alternatives to control pests and diseases.

MAFF and local authorities are making great efforts to control more pests and diseases with the existing substitutes and recommend farmers to use alternatives to this fumigant.

III. ALTERNATIVE METHODS TO METHYL BROMIDE USED IN JAPAN FOR SOIL TREATMENT

Chemical control

A. Soil fumigants

The following fumigants are currently used in Japan:

1. Chloropicrin
2. 1,3 dichloropropene
3. Mixture of chloropicrin (40 %) and 1,3-D (52 %)
4. Mixture of chloropicrin (50 %) and 1,3-D (25 %)
5. Metam-sodium
6. Metam-ammonium
7. Methyl isothiocyanate
8. Methyl isothiocyanate + 1,3-D
9. Methyl isothiocyanate - DCIP

Fumigants are generally expensive and therefore farmers decide whether to carry out a soil treatment, or not, depending on the profitability of the crop and the severity of the damage by soil-born diseases and nematodes, due to the repeated cultivation of the same crop. Fumigants other than MeBr do not show better efficacy against nematodes, fungi, bacteria, viruses and weeds altogether. A mixture of chloropicrin (40 %) and 1,3-D (52 %) was recently registered in Japan. Choloropicrin is more effective against fungi and bacteria and 1,3-D against nematodes, therefore this formulation should effectively control pests and diseases altogether.

B. Contact type micro-granules

The most commonly used pesticides of this kind are:

1. Ethoprophos
2. Oxamyl
3. Carbosulfan
4. Pyraclofos
5. Benfuracarb
6. Fosthiazate
7. Dazomet

Fosthiazate and dazomet, contact pesticides used against nematodes, are currently the most widely used by farmers. Dazomet is very effective against nematodes, soil born diseases and weeds. However, unless it is applied properly, its application could cause phytotoxicity to the crop. On the other hand, it is extensively used as alternative in fields close to residential areas.

Systematic application of fostiazate after chloropicrin, or dazomet, seems to be very effective to control soil borne pathogens and nematodes. Nematodes, which survive from the first treatment, should be afterwards killed with the contact to the micro-granule of fosthiazate. Insufficient efficacy of chloropicrin and dazomet against nematodes is covered by fosthiazate

Physical control

1. Solar energy treatment (solarization)

In regions with high solar radiation, many farmers have gradually come to apply solar energy. This method of control seems to be one of the best ways for the control of soil pathogens. The efficacy in the control of pests and diseases depends upon the weather. In case of bad weather conditions, efficacy is usually lower. In order to exhibit the highest efficacy of this treatment against soil pests and soil-born diseases, it is necessary to use a sufficient volume of water. Some farmers are concerned with the trouble of the equipment to be used in greenhouses, since it is exposed to rust. Greenhouse facilities tend to degrade because of the high temperatures. Moreover, a water supply is indispensable and the treatment is lengthy. This treatment is not suitable for field where crops are planted during the summer.

2. Hot water treatment

This method was developed by Tsukuba National Research Centre. Water is boiled at 95°C and poured in the field. The treatment kills several organisms, including pests, pathogens, and weeds, and the effectiveness lasts up to three years in protected cultivation areas. It is necessary to improve the equipment producing hot water, reducing its size and decreasing its cost, in order to make it more affordable to farmers. This kind of treatment is not suitable for large areas.

3. Flooding

This is one of the most widely used methods in areas where eggplants, tomatoes, strawberries and cucumbers are cultivated. Soilborne diseases and nematodes are controlled. In the future, this method appears to be one of the most promising ways to control soil pathogens.

Pest control by cultivation type

1. Rotation with non-host plant

For the control of nematodes in taro (*Colocasia antiquorum*), yam (*Dioscorea japonica*) and other legumes, crop rotation is sometimes applied, but in the cultivation of the major root crops such as radish, carrot and chrysanthemum, cropping rotation is not applied. In cash crops, rotation is not usually applied for nematode control. The appropriate rotation must be identified in order to obtain the desired results. Rotation from sweet potato to taro, or burdock, which are all root crops, does not make sense for the control of nematodes. Instead, combination of root crops and paddy rice is efficient to control nematodes in the soil, because of the unfavorable conditions to their life obtained with soil inundation.

2. Rotation with nematode antagonistic plants

Oat grass, ginia grass, sorgo, marigold and crotalaria are antagonistic to nematodes and are used to control nematodes attacking the roots of several crops. However, this method is not popular among the farmers. It is labor intensive, these grasses need time to grow and their efficacy seems to be only partial in case of high population densities of the nematodes. Furthermore, the long time needed for the cultivation of these grasses (three months, and then an additional month in the greenhouse) does not allow an efficient use of the greenhouse facilities.

3. Use of resistant variety or rootstock

Varieties, or rootstocks, resistant to nematodes have been developed only for tomatoes and eggplants. This method is popular among farmers. It is effective, but some new nematode races appeared and in some places the resistance has been overcome.

Biological control of nematodes

Formulations of natural enemies are used in Japan to successfully control nematodes.

- The fungus *Monacrosporium phymatopagaum* (Drecheler) Subramanian was registered to control the nematode *Meloidogyne incognita*.
- *Pasteuria penetrans* (Pasteuria wettable powder) is a bacterium which invades the body of the host, inhibiting nematode activity and reproduction. The spores of this bacterium are very resistant under a wide range of temperatures and dry conditions, being able to survive several years in the soil. It can build up large populations and is able to control nematodes for many seasons. In case of serious nematode attack, it is recommended to use it together with chemical nematocides, except chloropicrin and MeBr. For the control of soilborne diseases and nematodes, chemical fungicides and nematocides must not be used together with this bacterium. With the continuous cultivation of the same crop in the same field, the populations of this bacterium in the soil increase and are able to control nematodes. Once the population of the nematodes are reduced, the efficacy of *P. penetrans* lasts very long. Pot test data showed that it was still effective after nine years. Currently its cost is still too high to allow a generalized use by farmers.

Combination of existing methods

The improvement of the quality of products, the use of labor saving practices and lowering costs are major agricultural goals. Farmers tend to grow repeatedly the same kind of plant in the same field, resulting in the development of large nematode populations and heavy reduction of the yield. The continuous cropping pattern, which is prevailing among farmers growing cash crops such as tomato, pepper and melon, are likely to result in large nematode populations. Existing alternatives do not exhibit quick and excellent efficacy and durability as MeBr does. For existing alternatives, it is difficult to control both soil-born pathogens and nematodes with a single substitute. Therefore it is necessary to combine the existing pest control methods to reduce the nematode populations down to an acceptable level of damage. We have to use this approach for the development of alternatives to MeBr.

IV. CURRENT USE OF THE MAIN AGRICULTURAL CHEMICALS FOR SOIL TREATMENT

Chloropicrin, 1,3-dichloropropene (1,3-D) and MeBr are the mosty widely used agrochemicals (Table 2) with the share of 84 % in 1991. However, this figure comes down to 73 % in 1997. Even though chloropicrin and 1,3-D and their mixture have occupied rather big share, the use of metam sodium, dazomet and fosthiazate increased and farmers have been accustomed to use them effectively.

Table 2. Volume of sales of agricultural chemicals for soil treatment (tons)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999
Methyl bromide	6269	6594	7241	7782	5742	5559	5470	5336	4391
Chlorpicrin	5725	5732	6624	7433	8332	8533	8907	8802	8891
1,3-D	12694	13856	14015	13205	12344	10976	12951	12187	11889
MITC	1018	979	940	973	942	897	884	811	71
Metam sodium	-	-	-	28	65	234	202	199	210
Dazomet	769	915	1061	1323	1542	1607	1923	2194	2719
Oxamyl	3007	3162	2816	2743	2627	2546	2474	2126	2288
Fosthiazate	-	-	1034	1886	2661	3854	4707	4986	5815

* Source: MAFF Plant Protection Division

V. RECENT TRENDS FOR THE DEVELOPMENT OF ALTERNATIVES

In order to encourage the use of alternative methods to the use of MeBr, the range of application of the existing pesticides is being expanded and they are being registered for all suitable target pests. Considering the fact that at present new chemicals are not easily developed, this approach is rather useful for the development of alternatives, along with the combination of existing pesticides. Those combinations might be as effective as MeBr. Generally speaking, the cost is the key factor for the choice of alternatives by the farmers.

In 1999 the mixture of 40 % chloropicrin and 52 % of 1,3 dichloropropene was registered. It has excellent efficacy for the control of arthropod pests, diseases and weeds. In addition, the special formulation makes it far less irritant than regular chloropicrin.

Dazomet is one of the promising substitutes which many researchers consider effective to the pests, soil born diseases and weeds altogether. It is formulated as micro-granules, so it does not need irritating additives for its safe use.

Although metam sodium has been already registered, it is now under review for registration of a new formulation for better application. This pesticide needs a lot of water to be effective. Abundant watering before and after the application allows metam sodium to diffuse uniformly in the soil.

There are the three kinds of pesticides which can be used as pre-planting treatments: MeBr, which is a gas, and Chloropicrin, 1,3 D and metam sodium which are liquid. Dazomet is in micro-granules.

Despite different formulations, the active ingredient works invariably as gas in the soil. This gas itself might be phytotoxic, so it is necessary to remove it from the soil before planting.

In some prefectures the so-called Orugaloi film replaces polyethylene transparent films. This film is composed of several layers of polyamide and polyethylene, which have the property of being impermeable to MeBr gas and it is used to reduce the emission of MeBr into the atmosphere. Using such a plastic material it is possible to significantly reduce the rates of any chemical used as fumigants. The problem is that this material is much more expensive than conventional polyethylene transparent sheets and this prevents its extensive use by farmers.

- Solarization is popular among the growers of melons, strawberries, tomatoes, etc. It is quite effective in the region with high solar radiation during the summer. This treatment is very easy and cheap, so the farmers use it whenever possible.
- Flooding is also applied as the pre-planting treatment for strawberries, to kill pests and diseases in the soil.
- Grafting on resistant stocks is also feasible for the cultivation of tomatoes, melons and watermelons. It is also effective against pests and soil born diseases.
- Currently seedling dealers generally sterilize the soil of nurseries to grow pest free seedlings for sale.

CHAPTER V: AFRICA

PROMISING ALTERNATIVES IN KENYA AND MOROCCO

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Summary. In Kenya the importation of MeBr is decreasing, as result of the use of alternatives to this soil fumigant. Also in Morocco other means to control soil pests are being used. Growers are using cultural practices, other pesticides, Negative Pressure Soil Steam Sterilization, soil solarization in combination with fumigants, and biofumigation. These alternatives also proved to be cost effective.

Key Words: Methyl Bromide, alternatives, cultural practices, sanitation, steam sterilization, soil solarization, biofumigation

I. INTRODUCTION

Kenya is one of the countries in Eastern Africa with high consumption of MeBr as a soil fumigant to control soil-borne pests (diseases, nematodes, insect pests, weeds etc.) in the production of cut flowers (carnations, roses, and aster and chrysanthemum cuttings) and strawberries (Schonfield, Wamukonya and Glendening, 1994). The use of MeBr in cut flowers and strawberries is popular with growers because of its effectiveness in controlling a wide range of soilborne pests, cost effectiveness and ease of use. However, since the introduction of the Montreal Protocol in 1992, Kenya committed herself to the principles of the Protocol to phase-out the use of MeBr by the year 2015. As a result, the annual importation of MeBr stabilized at about 330 tons per year between 1994 and 1996, with 70 % of it used for soil fumigation in cut flower production (Klijnstra, 1999). During the same period, the combined total acreage under carnations, roses and chrysanthemums, the main crops requiring the use of MeBr, increased by 26.5 % (Malins, *et al,* 1998). It can therefore be assumed that the total consumption for soil fumigation is declining as well. The phase-out will in no doubt affect production and export of cut flowers and strawberries. However, continued use will have negative economic impact mostly as a result of International trade restrictions. To address the issue and to avoid the consequences of non-conformity to the Montreal Protocol, Kenya farmers and research institutions have been actively developing and validating suitable alternatives to MeBr for use in Kenya production systems (Klijnstra, 1999). The cut flower and strawberry production sub sectors are highly privatized and the flow of technical information is minimal (M. Wabule and R. S. Malik, personal communication). Many of the growers, particularly the large-scale farmers, carry out on-farm validation of suitable MeBr alternatives to address farm needs, and the information so generated is not available to the public. Thus, the reduced imports of MeBr as discussed above are evidence of declining demand for the product within Kenya, although the consumption for soil fumigation does not show a proportional decline. The observed reduced demand is evidence to the fact that the large users of MeBr are gradually becoming less dependent on the chemical as they embrace new alternatives in their production systems.

In Morocco, the use of nematicides increased from 300 tons in 1986 to 2000 tons in 1993. Among these nematicides, metam sodium and MeBr are widely applied in soil fumigation of tomato grown under plastic houses. Because they are difficult to handle, the granulars are occasionally used at planting time, even in combination with resistant, or tolerant varieties to root knot nematodes. Repeated use of nematicides on tomato and other cash crops have resulted in an accelerated bio-degradation of these chemicals and their failure to control *Meloidogyne spp*. Subsequently the application rates became very high compared to the recommended doses. These failures to control heavy root-knot nematode infestations associated with tomato growing in sandy soils under greenhouse conditions have encouraged the use of MeBr. MeBr was introduced for the first time in Morocco in 1952 and was used only in quarantine for controlling pests associated with agricultural products. In 1987, the use of MeBr (2 % Chloropicrin) was extended to soil disinfestation. The importers are also the distributors and the only authorised institutions to apply MeBr. The consumption of MeBr in 2000 was estimated at 1295 tons. Most of this consumption is used for soil fumigation and only a small amount (about 500 kg / year) is used in quarantine. The method of application is the one commonly known as "hot gas method": MeBr is vaporised in a heat exchange device and delivered as a gas to the field to be fumigated, in a perforated polyethylene tubing pre-placed on top of the soil before spreading the plastic sheet. The application rate of MeBr varies from 70 to 90 g / m^2 depending on the pests presents in soil. It is applied either locally, only on seed bed, 80 - 100 cm wide, or as an overall treatment to the whole field. The first option is the most common. This second technique uses approximately 700 Kg of MeBr per hectare compared to 300 Kg / ha as local application.

Most of the crops requiring soil fumigation are those conducted under plastic houses such as tomato, melon, watermelon, cucumber, strawberry, banana, and carnation. The period of application could be throughout the year but most of the treatments are concentrated during June-August, depending on the nature of crops conducted under plastic houses. The major soil pests controlled by MeBr are commonly root-knot nematodes for vegetable crops, ornamentals and fruit crops and occasionally *Fusarium* and *Verticillium* wilts. In Morocco, validated alternatives to MeBr in soil disinfestation were selected among others in the tomato sub-sector. Results obtained along a UNIDO (MP/126/MOR/97) demonstration project are reported. This project was implemented during the period 1998-2000. The alternatives described were tested on soils severely infested by root-knot nematodes (*Meloidogyne javanica*) and within an Integrated Pest Management (IPM) strategy.

II. KENYA[1]

Cut flowers

Alternative chemical pesticides

About 7 % of the KFC members have replaced MeBr with dazomet and another 14 % are practising IPM (KFC personal communication).

Use of soilless culture

A few growers are converting their production systems from soil based to hydroponics (personal observations, KFC personal communication). The most common substrates used by these large growers include pumice (locally mined in the production vicinity), and coconut husks (imported as cocospeat from Asia).

One farmer who has been growing roses using pumice as a substrate over the last 10 years, has completely eliminated the use of MeBr. Replanting was done without any soil treatment and there was no outbreak of soilborne pests in the new crop.

The use of cocospeat is a new introduction in the cut flower industry in East Africa and many farmers are still at the experimental stage. According to a farmer, who has been trying it out during the last three years, the use of cocospeat is 30 % more expensive than soil based systems, (needs frequent collection of technical data to optimise the approach and uses higher amounts of fertiliser) but gives more stems / m^2 which are also of better quality. The other limitation to wider use of cocospeat is local availability. The experimental material being used in the farms is imported from Asia, notably Indonesia and Sri-Lanka.

Use of natural pesticides

Mexican marigold, *Tagetes* sp., has also been tried by some farmers for the control of root-knot nematodes (Patel, 1999; Klijnstra, 1999) in cut flower production. According to Patel (1999), the use of *Tagetes* extract gave effective control of root knot nematodes in commercial roses. Similarly, using *Tagetes* as a fallow crop prior to planting roses delayed the onset of pest infection on mature roses while incorporating chopped material of the weed in the soil prior to planting improved the health of the plants and reduced attacks by root knot nematodes. The farmer found out that the best results were obtained when the chopped material of the plant were incorporated into the soil in combination with the application of an appropriate pesticide.

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[1] The alternatives described herein refer especially to large- and medium-size farms.

Compost

A farmer has tried a combination of metam sodium and mushroom compost for two years and coconut compost (locally bought from the Coast) for about 4 years in the production of cala lilies. Coconut compost is a by-product of coconut processing, mostly the sawdust, which is left to undergo natural decomposing.

Currently, the farmer uses the coconut compost as manure and in this allowed him to reduce the consumption of synthetic fertilisers by 30 to 40 % and also reduced soilborne pathogens. The farmer finds the coconut compost much cheaper than mushroom compost. The coconut compost has good water holding capacity and therefore can also be used in hydroponics. Metam sodium is used for soil fumigation once a year in the production of bulbs to minimise the outbreak of soilborn pathogens, particularly before planting a new crop.

Strawberries

The majority of small-scale farmers use cultural methods to control the major soilborne pest problems (Mungai, 1995).

Use of clean planting materials

This is has been accepted by growers and is widely practised even by medium and large growers.

Mulching

Farmers are advised to use black polyethylene mulch as this gives effective weed control. The black polyethylene also helps to conserve soil moisture, keeps the soil warm and the fruits clean.

Sanitation

This involves the removal and burning of crop residues after every two months of continuous production.

Crop rotation

A two to three year's rotation is advised. Farmers should start with clean planting materials.

Roguing

Uproot and destroy all plants affected by viral diseases. However, the recommended cultural practices have not offered solutions to all soilborne and viral pathogens that constrain economic production of strawberries. Medium and large growers (> one acre under production) have been experimenting with other pest control methods that will ultimately be able to replace MeBr in the production of strawberries.

Chemical pesticides

One particular farmer uses metham sodium for soil fumigation once every two years i.e. the pesticide is applied after uprooting the old crop and before the new crop is planted. In this way the outbreak of soilborne pests has been minimized.

Mushroom compost

Mushroom compost, bought locally from mushroom growers, when added in the soil at the rate of 4-6 cubic metres / 1000m^2 before planting, as a source of plant nutrients, was found to give effective control of soil pests, particularly weeds and plant diseases (two years experience by a strawberry grower). The compost is much cheaper than farmyard manure and gives better returns.

Mulch film

This has been found very useful for the control of insect vectors of viral diseases. However, at the moment, this approach is only available to the medium and large strawberry growers because the mulch film material is not locally available. The sample used for experimentation was imported from Israel.

III. MOROCCO

Protected crops

The following alternatives are used in protected crops:

2.1. Negative Pressure Soil Steam Sterilization (NPSSS);
2.2. Soil solarization in combination with fumigants (1,3 D, or metam sodium); and
2.3. Biofumigation.

2.1. Negative Pressure Steam Soil Sterilization (NPSSS)

In Farms dedicated to a very early production, plantation occurs in early August to produce and export in October. Soil preparations (cleaning from previous crop remains, plough, irrigations etc.) prior to soil disinfestation are required in June. Under these circumstances, the selected alternative has to take into account the short period available for soil disinfestation. To this end, steam sterilization is appropriate.

The performance of conventional sheet steaming is limited in sandy soils of Morocco. Appropriate temperatures (70°C) are obtained only in the first 10 - 20 cm of the soil profile. On the other hand, the Negative Pressure technique generates appropriate soil temperature at a 60 cm depth and complete control of nematodes, fungi and weeds is achieved. In this technique, the steam is introduced under the steaming sheath and forced to enter the soil profile by a negative pressure. The negative pressure is created by a fan that sucks the air out of the soil through buried perforated polypropylene pipes. This system requires a permanent installation of perforated pipes into the soil, at a depth of at least 60 cm to be protected from plough. To determine the exact time of treatment (which greatly determines the economic feasibility of the technique), the soil temperature has to be monitored at different levels during the treatment.

The technical advantage of the system is that the whole area to be occupied by the roots of the plants is effectively treated and protected from root-knot nematode re-infestations throughout the cropping cycle. Also, since the time to treat an area unit is much shorter compared to the conventional sheet steaming technique, the operational costs (fuel and water consumption) of NPSSS are much lower and are considered economic for the production of a very early produce. However, the technique needs an initial investment to install the negative pressure piping and the steam generators.

2.2. Soil solarization in combination with chemical fumigants

Under Moroccan conditions, fields tests carried out on soil solarization along the coastal area, during July - September 1982, 1987 and 1992, resulted in top-soil-layer temperatures above 50°C and 43 - 49°C at the first 10 - 20 cm of the soil profile and induced 60 % decrease in root–knot nematode populations. Under laboratory conditions, after a two-week exposure to 40°C, the infection potential of *Meloidogyne javanica* is completely eliminated, but hatching of eggs, although drastically affected, is not totally eliminated. Continuous hatching of eggs even under high soil temperatures permits early re-infestations which are originated from deep soil profiles with soil temperatures below 40°C and limits the effectiveness of solarization when applied alone. Because of these constraints which limit the effectiveness of solarization used alone, it was established as an effective practice and viable alternative to MeBr when applied as part of an IPM program.

Two chemical fumigants, with different properties (1,3-dichloropropene and metam sodium) were chosen to complement soil solarization. Metam sodium is applied to the soil using the existing (modified) drip irrigation system. A manifold of dripper pipes, spaced by 40 cm and each containing 4 l / h drippers spaced by 50 cm, is used. Drip irrigation system is already available in most of the farms and will need to be adapted for a safe chemical application, for a broadcast application (to avoid re-infestations) the irrigation lines will need to be doubled, a tank and a injection device is also needed. The application rate of metam sodium is about 5 l / m^3 water, to apply 50 g / m^2 soil, corresponding to 100 m^3 water / ha and 500 l of metam sodium (1000 kg / ha of the 51 % formulation, which is registered in Morocco).

1,3-Dichloropropene will be applied using a special device for soil injection. After each treatment, the soil is immediately covered by clear polyethylene film, brought to the field capacity and left under solarization for 4 weeks instead of at least 6 weeks as required for a conventional solarization. Soil solarization combined with 1,3-Dichlorpropene is highly recommended where only root-knot nematodes are a major soil problem. Metam sodium is a poorer nematicide but in contrast is a good herbicide and fungicide.

2.3. Biofumigation

Bio-fumigation is often combined with the use of plastic tarps or other soil covers to raise soil temperature and to retain gases generated during the biofumigation process. In this way, the lethal effect of soil bio-fumigation on soilborne pests and diseases is caused by a combination of the direct effect of toxic substances from the decomposing bio-fumigants, and the long-term increase of soil temperature. Many soilborne organisms will be controlled and / or made more susceptible to hyper-parasitism by prolonged exposure to the sub-lethal temperatures obtained. Soil bio-fumigation need to be monitored to ensure that exothermic fermentation process is achieved and that appropriate temperature is reached and maintained over time. For an effective treatment, careful guidelines must be closely followed.

The soil must be well tilled to destroy clods and plant debris, which might interfere with uniform conduction of heat and bio-gases, and which might protect some organisms that could escape control. The bio-fumigant has to be chosen among available materials from the area (cost depend largely on availability and on transportation costs). Typically, an organic amendment partially decomposed with C : N ratio > 11 would be adequate. The dosage of bio-fumigant is variable ranging from 70 to 140 t / ha. It is recommended to place the bio-fumigation material in a layer at 10 to 20 cm from the soil surface, this layer is then covered with the soil, watered to start fermentation and usually covered with a plastic tarp. This technique needs a drip irrigation system installed under the tarp for an overall irrigation. To this end, the existing irrigation system will need to be modified and the irrigation lines will need to be doubled.

Soil bio-fumigation controls certain weed species, nematodes and a variety of soilborne diseases caused by fungi. This technique, when applied as part of an IPM program, is a viable alternative to MeBr.

Integrated Pest Management (IPM)

Basically the IPM programme includes:

Monitoring and identifying pests: IPM programmes work to monitor root-knot nematodes and identify them accurately, so that appropriate control decisions can be made in conjunction with action thresholds already established about 100 larva / 500 g of soil. This monitoring and identification removes the possibility that pesticides will be used when they are not really needed, or that the wrong kind of pesticide will be used.

Prevention: IPM programmes work to manage the crop to prevent pests from becoming a threat. This may mean using the right selected alternative with pest-resistant varieties, and planting pest-free rootstock. These control methods can be very effective and cost-effective and have little to no risk to people, or the environment.

Control: Once monitoring, identification, and action thresholds indicate that pest control is required and preventive methods are no longer effective, or available, IPM programs then evaluate the proper control method both for effectiveness and risk. The selected alternative is implemented . Also during the project, plastics will be recycled using the recycling factories available in the country, this recycling will also provide some extra savings to the farmer.

Therefore, the implementation of the IPM approach will require a well trained technical personnel in the field, able to assess the technical capabilities of farmers, farm infestation levels and, who has an adequate knowledge for environment to monitor pests and treatments.

Yield and performance of alternatives

The techniques alternative to MeBr were selected on the base of their technical and economic feasibility. They were tested during two cropping cycles (1998 - 1999 & 1999 - 2000) and included root-knot nematodes population dynamics (Table 1) and yield performance (Table 2). The integrated pest management programme included the determination of specific soil preparation practices aimed at maximizing the effectiveness of the proposed alternative.

After soil disinfestation during summer, prior to planting, the selected alternatives eliminated initial root-knot nematode populations and give similar

Table 1. Effect of MeBr alternatives on root-knot nematodes (*Meloidogyne javanica* juveniles / 500 g of soil), during two crop seasons: 1998-1999 & 1999-2000

	Before planting[a]		After planting, during the crop		
	June	August	Sept. - Nov.	Dec.- Feb.	March -May
Control	550	392	1024-9225	2015-2311	1927-3475
Methyl bromide	560	00	30-50	77-50	74-174
Bio-fumigation (6wks)	585	00	430-1720	2116-1270	1170-982
Metam Na+Solariz. (4wks)	480	00	254-10806	455-430	560-2542
1,3 D+Solarization (4wks)	635	00	32-1830	55-70	94-514
Negative Pressure Steam Soil Pasteurization	630	00	69-121	57-47	59-39

[a] Values for June are before treatment and correspond to P_0; Value for august corresponds to the nematode population after the treatment P_f.

results to MeBr. However, during the circle period following plantation, September – November, re-infestation are relatively higher in soil treated with bio-fumigation and solarisation in combination with metam sodium compared to MeBr, solarization combined with 1,3-D and sheet steaming. Re-infestation during this period affect vigor, growth, flowering, fruiting and subsequently the quality and the quantity of the yield. Therefore any other action should occur during this period to maximize the efficacy of these alternatives.

During December - February, root-knot nematode populations drop naturally because the soil temperatures are below 20°C, and do not affect the yield. At the end of the production, the yield is already established and late infections affect the roots, but not the production. Statistically, yields differ significantly from the control, but not among the rest of the treatments including MeBr.

The IPM applied together with the alternative techniques included practices directed at enhancing nematode egg hatching, fungus spores, mycelia, or other conservation forms and to favor the germination of weed seeds, optimizing chemical diffusion, increasing and maintaining soil temperature during solarization, etc. As re-infestation and spread of nematodes and other soil borne diseases may occur by plant material and compost, or organic manure, the seedlings were carefully inspected and free of any infection (certified pest-free) and organic manure sterilized, or with composting process carefully monitor.

Table 2. Yield comparison for MeBr alternatives applied to tomato Daniela grafted on Beaufort

Selected alternatives	Yield decrease (%)[a]
Control	**18**
Methyl bromide	**0**
Bio-fumigation (6wks)	**6**
Metam Na+Solariz. (4wks)	**8**
1,3 D+Solarization (4wks)	**4**
Sheet Steaming soil sterilization	**1**

[a] As compared with the MeBr treated plots.

Acceptability to regulators and markets

The selected alternatives do not require any regulatory approval. The harvested vegetables are more acceptable to supermarkets and purchasing companies than those grown using MeBr, because solarization does not involve the use of toxic materials and reduces the companies' risk of criticism by consumers and the media.

Costs

Costs are basically estimated on labor involved (prior, during and after application of each selected alternative), the chemical, plastic, fuel and organic manure necessary to accomplish each alternative. Overall, solarization alone (bio-fumigation), or in combination with an application of metam sodium, or 1,3-D, is slightly more expensive compared to MeBr applied only to the planting beds at 350 kg / ha. However, the estimated cost for steam sterilization was low compared to MeBr. This cost includes only fuel and labor and does not include the investment for the steamer and the soil equipment for negative pressure. Economic studies based on local market and export values revealed the effectiveness of the selected alternatives as compared with MeBr.

Applicability to other regions

Negative Pressure steam sterilization is an environmentally safe and sustainable technology in soil disinfestation. It was basically developed as an alternative to MeBr in Holland and also in Syria. Its application is highly recommended in sandy soils. Solarization alone, or bio-fumigation as presented in this report is being used with success in Mediterranean climate during at least 6 – 8 weeks to control rot knot nematodes. Solarization in combination with metam sodium, or 1,3 dichloropropene, could be applied wherever solarization alone is possible, but under severe root-knot infestations and where the cropping cycle, and the climatic and soil conditions enhance the multiplication of nematodes.

Table 3. Compared cost estimates in $US of methyl bromide and selected alternatives for tomato

Item	Methyl	[a]Bio-	[b]Solar.+	[c]Solar.+1,	[d]Steam

	bromide	fumigatio n 6-8wks	MeNa (4wks)	3D (4wks)	sterilizatio n
Chemicals for treating soil	1400	0	1500	1645	0
Plastic sheets for soil or fuel	420	728	728	728	1815
Labor for soil preparation and treatment	1155	2520	1255	1245	460
Total	2975	3273	3483	3618	2275
Incremental costs		298	508	643	-700

[a] 70 tons of organic manure (90 tons) and soil solarization during 6-8 weeks.
[b] Soil solarization combined with metam sodium (1000 l / ha) applied in drip irrigation during 4 weeks.
[c] Soil solarization combined with 1,3 dichlororpropene (400 l / ha) injected at 25 cm soil depth, for 4 weeks.
[d] Soil sterilization using either sheet steaming, or negative pressure technique.

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CONCLUSIONS AND RECOMMENDATIONS

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1. From the reports given in this material it is clear that scientific and technical institutions have carried out a huge work looking for the development of new alternatives to replace the present use of MeBr as soil fumigant.

2. In some countries, such as Spain and USA (Florida) it is evident the existence of various validated alternatives that can be used immediately by growers in several high-income crops, such as strawberries, tomatoes, peppers and others.

3. Brazil has executed an excellent work on tobacco and in the implementation of float tray for growing tobacco seedlings. This soilless technology has been previously developed in USA temperate areas and still may need some modifications for its adaptation to other hot-climatic environments, e.g. to define the need to use plastic film cover, which may increase plant transpiration and, subsequently, decrease plant vigour.

4. In general soilless alternatives need a heavy initial investment for their implementation and also good technical services. Not all farmers may afford these methods unless donors or governments provide an initial investment, which should come with a regular technical assistance regarding the substrate, nutrients to be given and additional pest control.

5. Some alternatives although effective are not always a guarantee of pest control efficacy. This is the case of soil solarization, which highly depends on prevailing air and soil temperatures. If the temperatures are not high the method may fail to control soil-borne pests and this may be a risk for farmers' production. Combination of soil solarization with other methods seems to be a feasible way to increase the effectiveness and to reduce the uncertainty of solarization alone.

6. A very effective method is biofumigation provided that organic waste, manure, etc are available in farm areas. Biofumigation well managed seems to have less problems of uncertainty than soil solarization. The method itself is also environmentally safe. In some areas the method cannot be implemented if there is no enough organic waste to use.

7. Crop rotation is a well-known control measure with a high degree of effectiveness, but the problem is that normally farmers using MeBr are those growing high-income crops. Therefore it is doubtful that they will adopt widely this practice because crops involved in the process of rotation will never give the same income as those currently treated with MeBr.

8. The use of resistant cultivars and grafting are suitable measures to be integrated in the control system to be adopted. These methods are specific to control particular pests but not the whole complex.

9. In Japan, an economically wealthy country, there are other possibilities using water as the main control agent. The Japanese institutions have developed a generator of hot water, which is highly

effective in soil-borne pest control and is used in several seedbeds and nurseries. Flooding is also a viable alternative in this country.

10. The Japanese use also a plastic film, which is non permeable and enables the farmers to reduce the rates of MeBr and also of other chemical fumigants. The problem of this new synthetic material is its present high price.

11. The use of chemical fumigants, such as metham sodium, dazomet, 1.3 dichlorpropene, chlorpicrin, is another possibility, but the use of any of these chemicals will highly depends on the economy of farmers. In addition, farmers should take various measures of safety to handle and apply these chemicals, some of them as toxic as MeBr. A possibility is the use of any of these fumigants at reduced rates combined with other physical control methods, e.g. soil solarization.

12. Integrated pest management (IPM) is a real possibility provided that farmers will have an idea of the main soil-borne pests present in the soil. With such knowledge it is possible to implement specific control measures or low-toxic pesticides aiming at the direct control of those really present organisms in soil, be nematodes, weeds or any other pathogens. IPM requires knowledge of main pest organisms by farmers and not only of possible control measures to be implemented.

    For best IPM performance in areas traditionally treated with MeBr it is indispensable to develop a training process with large participation of agricultural extensionists and farmers.

13. Developing countries still need to develop their own alternatives and the process of adoption of new alternatives can be speeded up with farmers' training combined with validation of alternatives. Instead of having separate demonstrations where farmers do not participate at all, it is necessary to have an approach where farmers will learn and at the same time adapt the proposed alternatives. By this way money used for introduction of new alternatives into the agricultural practice will be efficiently used.