

# NON-CHEMICAL ALTERNATIVES USED IN THE USA ON HORTICULTURAL CROPS

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## ABSTRACT

A variety of non-chemical alternatives to methyl bromide (MB) fumigation of soil for horticultural crop production have been researched in the USA. Non-chemical alternatives are highly desirable but difficult to implement to reproduce the benefits normally obtained by preplant fumigation of soil in strawberry production. Production of pathogen-free, high-quality planting materials using steam and other physical methods of soil disinfestation have not been perfected for large-scale runner plant production. Genetic resistance or tolerance to specific soilborne pathogens is important and can be improved. While crop rotation improve strawberry yields and in some cases reduced soilborne disease, the high cost of land and infrastructure for strawberry production precludes rotation as an option. Solarization, biofumigation and/or organic soil amendments have been tested but have have not been successful. Soil amendments must be used at relatively high rates for effects to be significant, and the results have been variable between years. Beneficial microorganisms to enhance strawberry production have produced highly variable results. In general, further research is needed to further optimize and integrate nonchemical alternatives to MB.

**Keywords:** Non-chemical alternatives, steam, genetic resistance, crop rotation, solarisation, biofumigation, soil amendments, beneficial microorganisms, strawberries

## INTRODUCTION

A variety of non-chemical alternatives to methyl bromide (MB) fumigation of soil for horticultural crop production have been researched in the USA. Unfortunately, it is generally difficult to reproduce the high levels of soilborne pathogen control, weed control, and yield stimulation normally obtained in horticultural systems with MB and other soil fumigants by non-chemical methods. This is especially the case for high-input, high-value crops such as strawberries, tomatoes, peppers and flowers grown annually on the same ground. As a result, non-chemical methods have generally not replaced soil fumigation in most large-scale horticultural crops where MB has been used in the USA. While this case study will focus on strawberry production in California, many of the conclusions apply to other horticultural crops. Replant disorders of woody perennials, however, may be somewhat different and will not be considered specifically.

An important measure in horticultural crop production is to start with pathogen-free, high-quality planting materials. This is achieved to a large extent in strawberry by producing runner plants in fumigated nursery fields. Plug or container plants can be produced using artificial or heat-treated substrates as an alternative, but it will be difficult, if not impossible, to meet the full demand for strawberry transplants by these methods. Steam and other physical methods of soil disinfestation have not been perfected for large-scale runner plant production, and soil fumigation with MB or chemical alternatives is likely to be needed indefinitely for some phases of strawberry nursery production.

Genetic resistance or tolerance to specific soilborne pathogens can be important. For example, some California strawberry varieties have helpful levels of tolerance to *Phytophthora* root and crown rots (Browne *et al.* 2001). None of the current varieties, however, has sufficient tolerance to *Verticillium* wilt (Duniway *et al.* 2001). Equally important, the general yield response of strawberry to soil fumigation involves reductions in a number of other fungi damaging to roots (Duniway *et al.* 1999; Martin 2001). While California varieties differ in their responses to these fungi and to nonfumigated soils (Martin 2001), there is considerable debate about the prospects for developing strawberry varieties that can achieve the current high yield potential and berry

quality without soil fumigation. There is little doubt, however, that genetic tolerance to specific soilborne pathogens can be improved.

Crop rotation can improve strawberry yields and in some cases may reduce soilborne diseases. For example, one-year rotations out of strawberry with rye or two crops of broccoli improved subsequent strawberry yields on nonfumigated soil by 18-44% (Duniway *et al.* 1999, 2000). Fumigation of the same ground, however, approximately doubled yield. Broccoli rotation and incorporation is reported to reduce *Verticillium* wilt in subsequent crops, but results obtained so far in strawberry are variable (Duniway *et al.* 1999, 2000). While crop rotation is highly desirable, the high cost of land and infrastructure for strawberry production in coastal regions of California usually leads to annual plantings of strawberries on the same ground.

A variety of nonchemical soil treatments have been tried for strawberries in California, including solarization, biofumigation and/or organic soil amendments. Because of seasonal coastal fogs, only a small fraction of the acreage used for strawberry production in California has a climate that is suitable for solarization at the time it would be needed. A variety of soil amendments have been used with mixed results. Composts are used routinely in organic production (Bull 1999), but they have not generally given significant yield increases or disease suppression when applied in conventional strawberry production systems (Duniway *et al.* 1999). High-nitrogen organic amendments, such as blood meal, can reduce *Verticillium* wilt significantly, but can also cause phytotoxicity (Duniway *et al.* 1999, 2000, 2001). Furthermore, soil amendments must be used at relatively high rates for effects to be significant, and the results have been variable between years (e.g. Duniway *et al.* 2000, 2001).

There is considerable interest in using beneficial microorganisms to enhance strawberry production in California. A variety of fungi and bacteria from commercial sources have been applied to bare-root transplants and/or through drip irrigation systems. While some of these inoculations increased yield in nonfumigated soils, more beneficial results were sometimes obtained in soil fumigated with chloropicrin (Duniway *et al.* 2000, 2001; Eayre 2001). In addition, some rhizobacteria isolated from strawberries grown in fumigated soils have been found to increase the growth and/or yield of strawberries grown in nonfumigated soil or soil treated with a low rate of chloropicrin (Duniway *et al.* 2000, 2001; Martin 2001). Inoculations of strawberry with mycorrhizae have given inconsistent results (Bull 1999). Unfortunately, the results obtained with biological controls or beneficial microorganisms to date have been highly variable and more research is needed to optimize their potential utility in strawberry production.

From environmental or social points of view, nonchemical alternatives to MB are highly desirable. From an agricultural point of view, however, they are difficult to implement to effectively reproduce the benefits normally obtained by preplant fumigation of soil in strawberry production. Obviously, more research is needed to further optimize and integrate nonchemical alternatives to MB. Strawberry production in California, however, is already a highly integrated and complex farming system using IPM strategies extensively, and it is unlikely that current levels of production can be achieved using only nonchemical alternatives to MB. It is more likely that some of the nonchemical alternatives can be used to augment chemical alternatives applied at lower rates by more efficient methods.

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## NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USED IN MEXICO

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### ABSTRACT

Watermelon exports from Mexico were valued at US\$7.0 million in 2000. MB has been used for watermelon production in Mexico since 1989 to control mainly root-knot nematode (*Meloidogyne* spp), soil-borne fungi, weeds. In 1998, approximately 435 tonnes of methyl bromide (MB) were used to fumigate 96 ha of watermelon seedbeds. As an alternative, solarisation seed trays, manure and growth promotors can substitute for MB. Seedlings were coated with growth promotor just before planting into a hole filed with chicken, cow or goat manure. Conventional insecticidal or fungicide was used to control plant pests. Weeds were manually eliminated throughout the growth season and one application of chemical fertilizer was applied manually or via the drip irrigation system. The alternative advanced the harvest and increased yield by about 30%. This alternative could also be used by cucurbit or tomato growers in Mexico and many countries with similar growing conditions. This system has eliminated the use of MB and plastic mulch in areas where weed and water problems are not limiting factors.

**Keywords:** watermelon, Mexico, methyl bromide, alternative, growth promotor, solarization, manure

### INTRODUCTION

The total production value of watermelons in Mexico was close to US\$232 million in 2000 (1,069,057t). About 28% of the crop was exported, mainly to the United States, bringing a return of US\$7 million. The case study focuses on production in the Rio Balsas watershed region and the Mixtec region both located in the south east of the state of Puebla and East of the State of Guerrero. Both regions are characterized by rivers, a river basin, small valleys with wells and irrigation systems, hills and mountains, and slight to steep slopes with gradients from 20-60 degrees. It is typical subtropical dry region with altitudes in the range of 500 to 1800 m above sea level.

#### Crop production characteristics

Generally in Mexico watermelon is grown by highly qualified grower that produces seedlings in a greenhouse or covered area before they are transplanted to the field. Normally the substrate used for seedlings is fumigated or steam sterilized. Some growers in the field use plastic mulch under drip irrigation or other type of irrigation. A great number of growers still prefer direct sowing and occasionally non-fumigant nematicides application because the relative high initial investment to adopt an alternative system. This implies technical advice, training, setting up drip irrigation system and plastic mulch.

In the Mixtec and Balsas regions watermelon is a traditional crop of small irrigated areas (1-3 ha) located around the rivers and land with small scale irrigation infrastructure, wheels and reservoir dams. Watermelon is grown on 2000 ha mostly sandy soils in about 800 family-run farms. There are a few commercial enterprises ranging in size from 10-20 ha.

#### Use of methyl bromide

MB has been used for watermelon production in Mexico since 1989 to control nematodes, mainly root-knot (*Meloidogyne* spp), soil-borne fungi, weeds. In the past, most growers who had difficulties controlling soil-borne pests with pesticides turned to MB because they found it more effective. It is primarily used to fumigate soil for seedlings in greenhouses and may also be used for partially protected seed-beds in the fields. In 1998 an area of seed-beds close to 96 ha was fumigated for watermelon at 454g/m<sup>2</sup> rate.

### Commercial use of alternative

Starting in 2000, 18 watermelon growers from both the Mixtec and Rio Balsas regions started to use solarised substrate (primarily coconut dust mixed with organic soil) for seed trays.

Seedlings are transplanted in the open field (3000 –3500 plants/ha) in a hole with 300-350 g of manure. During the first week the seedlings are treated with Horticplus® or endospore® (both biocontrol-plant growth promoters) in the foliage or through the irrigation system. The roots may be infected but at the end damage is acceptable since yield is marginal reduced. This system costs less than the production using MB and it is an excellent option for growers that cannot establish plastic mulch with drip irrigation in their production unit due to lack of capital. Plastic mulch can only be used in one season and their uneven land makes it difficult to lay down plastic sheets.

Typically, the following materials are required: Plastic sheets for solarisation of substrate; Substrate (coconut dust or volcanic grave mixed with organic soil); Seed-trays (60-77 cells) or 250cc polyurethane cups; Manure from chickens, cows or goats; Seeds coated with antifungal agents; Biocontrol-plant growth promoters.

Seeds are imported (generally from the USA) coated with antifungal treatment. No chemical treatment for substrate sterilisation is needed due to solarisation with white plastic sheets. Seeds are allowed to germinate in conventional seed-trays or polyurethane cups.

Conventional insecticide or fungicide is use to control top plant pests if necessary. Weeds are manually eliminated throughout the growth season and one application of chemical fertilizer is applied manually or via the drip irrigation system during the flowering period.

### Yield and Performance of Alternative

The conventional MB system used for watermelon in the Balsas region gives an average yield of 23 tonnes/ha. Using the alternative system yield increase to 35 tonnes/ha. The advantages of the system are given in Table 1, and the yield information in Table 2 when compared with MB. The alternative system prevented nematode and soil borne pathogen attack during the first 20-30 d after transplanting.

Table 1: Comparison of performance and benefits of alternative system and MB

SOLARIZATION SEED TRAYS, MANURE AND BIOCONTROL-GROWTH PROMOTERS	MB SYSTEM
Plants grow stronger and more uniform	Plants tend to be weaker and less uniform
High quality watermelons	Lower quality plants
Earlier harvest date	Requires an extra month growing period
Requires less chemical pesticides	Requires more chemical pesticides
Yield of 35 t/ha	Lower yield of 23t/ha
No significant worker safety issues	Worker safety concerns because MB is a toxic gas
Operation cost is cheaper over 3 years, but needs an initial investment to set up the system	Operation cost is higher, but initial capital investment is not required

This protected the roots during the most vulnerable plant stage. In addition, it improved top and root growth of watermelons plants giving a better and faster growth and advancing the harvest an average of 20 days.

Table 2: Comparison of watermelon yields using MB and Alternative system

Farm size	Yield using alternative	Yield using MB (t/ha)
1-3ha	35	23

Limitation of the alternative system is the lack of technical support to trainee rural growers to adopt the system. Intensive efforts are in progress to fill this gap seeking support from any government or non government agency. This alternative system for controlling soil-borne pests does not require regulatory approval because it does not use toxic materials. The yield increase and shorter growing period allows growers to arrive earlier in the market and to sell the product at higher prices.

Comparative costs between MB system and alternative system are summarized in Table 3. The alternative saves costs associated with the use of machinery, fertilizer and chemical pesticides. However the extra yield and the higher prices obtained at the beginning of the season make it a highly attractive system for growers. In addition using manure from rural activities is a better way to recycle natural organic waste. All the items (plastic sheets, seed trays, horticplus, endospore) can be obtained in major cities close to the regions.

This multi-tactic alternative system could also be used by cucurbit or tomato growers in Mexico and many countries with similar growing conditions. This system has eliminated the use of MB and plastic mulch in areas where weed and water problems are not limiting factors.

Table 3: Costs of using MB and alternative system (solarization of substrate, seed trays, manure, biocontrol) for watermelon production in Mixtec and Balsas regions.

ITEM	ALTERNATIVE SYSTEM US\$/HA	MB SYSTEM US\$/HA
Machinery	0	120
Labor	150	112
Seed	30	30
Fertilizer	50	230
Chemical pest control	500	620
Plastic sheet	20	20
Seed trays	30	30
Substrate	30	30
Watering	20	20
Fuel for water pump	70	70
	1020	1282

Source: Marban-M and Venegas-Bustamante, 1999.

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## NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE IN GREENHOUSE-GROWN SWEET PEPPER IN SPAIN

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### ABSTRACT

Sweet pepper cultivation in Campo Cartagena (Murcia) and Pilar de la Horadada (Alicante) is of great socio-economical importance as about 180,000 tonnes per year are grown on more than 1,880 ha. Trials tested rhizobacterium inoculated seedlings, biofumigation with solarization with different materials, rate and timing of application; grafted rootstocks tolerant to *P. Capsici* and *M. Incognita*; and soilless culture with organic substrates coming from the agrifood industry. Soilless cultivation, biofumigation with solarization and grafted plants, alone or combined, were considered alternatives to MB. The choice of one or other depended on the area and productive cycle, the degree of specialisation, the technical skills of growers and technicians, the level of technological development and the availability of sufficient manure or biofumigation material. The cost of non-chemical alternatives is likely to be similar to, or lower than, chemical alternatives.

**Keywords:** Biofumigation, grafting, sweet pepper, non-chemical alternatives, methyl bromide

### INTRODUCTION

This paper reports on non-chemical alternatives to methyl bromide (MB) in sweet pepper grown in greenhouses in Spain, and in particular research carried out in Campo Cartagena (Murcia) and Pilar de la Horadada (Alicante), classified by the European Union as less favoured areas. In this area, sweet pepper is of great socio-economical importance as about 180,000 tonnes per year are grown on more than 1,880 ha. The crop is fragmented into many small family holdings with an average land area of 1.6 ha.

Sweet pepper cultivation started in 1973 and currently the crop can be considered as a monoculture in this area. The crop starts with seeding in nurseries in October, soil transplant in November-December and harvest from March to September-October. The phytosanitary problem in soil used for pepper cultivation is due to *Phytophthora capsici*, *Meloidogyne incognita* and other problems of unknown nature caused by repeated cultivation of crops on the same land and a resultant decline in profitability. Since the beginning of cultivation, soil disinfection has been the usual practice. Disinfections were first made with metam sodium followed by the use of methyl bromide (MB) in 1985. The phase out schedule for MB reduction and elimination provokes an uncertain situation and uneasiness in the pepper production sector.

### METHODS

The Federación de Cooperativas Agrarias de Murcia (FECOAM) joined a programme with the Consejería de Agricultura, Agua y Medio Ambiente Centro de Investigación y Desarrollo Agroalimentario (CIDA) in the search for alternatives to MB in greenhouse pepper crop.

The importance of a production system that is respectful of the environment, such as the case with Integrated Pest Management Production (1,100 ha) and organic agriculture (32 ha), as well as the growers request for using clean technologies, made it necessary to direct research toward non-chemical alternatives that might resolve the phytopathological problems. One of these alternatives was the use of rhizobacterium inoculated seedlings, biofumigation with solarization with different materials, and rate and date of application; grafted, tolerant rootstocks to *P. Capsici* and *M. Incognita*; and soilless culture with organic substrates coming from the agrifood industry.

## DISCUSSION AND CONCLUSIONS

From trials carried out in the last three growing seasons in the Campo Cartagena greenhouses the following conclusions may be drawn:

- 1) Rhizobacterium applied to seedlings in nurseries did not give as good results as the usual MB disinfections.
- 2) Biofumigation with solarization was effective in controlling *P. capsici* and less effective in controlling *M. Incognita* than MB. However, neither yield nor plant development reduction were significant. Repeated applications over consecutive years led to an increase of pathogen control, weeds, yield and soil physico-chemical properties. Fresh sheep manure (4-7 kg/m<sup>2</sup>) with chicken manure (2-3 kg/m<sup>2</sup>) used for biofumigation was a limited resource that the local market was unable to provide. The best results were obtained when biofumigation was made at the end of September at the latest, although, at that time, the growing season was still ongoing. It was interesting to note that the incorporation of plant remains accounted for over 7 kg/m<sup>2</sup> of fresh biomass and helped to make up for the limited availability of sheep and chicken manure. The cost of the whole disinfection process was 0.35 €/m<sup>2</sup>. Currently, more than 40 ha of pepper commercial greenhouses use this disinfection method.
- 3) Grafted plants produced good control of *P. capsici* and *M. Incognita*. There are also firms that focus their research on developing tolerant or resistant plants to this pathogens. However, the technique was expensive and increased seedling cost to over 0,30 € per plant (0,75 €/m<sup>2</sup>) which led to a final price of approximately 0,51 € per plant. Grafted pepper plants have not been used commercially, contrary to the case of other vegetables grown in the area such as watermelon or tomato. When the technique is affordable, it would be interesting to combine it with other soil management methods to reduce or mitigate the soil exhaustion. The production sector is very optimistic about this technique as it is a biological solution to solve soil problems.
- 4) Soilless cultivation. It has been trialled with organic material, coconut fibre and agrofood industry subproducts such as rice husk and crushed almond shells. On the other hand there are materials from inorganic origin, such as perlite and rockwool, all of them giving successful results and higher profits than MB, when managed properly. However, a high technological investment is needed to increase the knowledge of growers and technicians. Moreover, soilless cultivation in pepper crops has yet to be calibrated to our agroclimatic characteristics. Currently, soilless culture accounts for less than 40 ha.

To conclude, we can say that the soilless cultivation, biofumigation with solarization and grafted plants, alone or combined, are alternatives to MB. The choice of one or other depends on different factors such as the area and productive cycle, the degree of specialisation, the technical skills of growers and technicians, the level of technological development and the availability of sufficient manure or biofumigation material. In this latter case, apart from offering a productivity guarantee, a product of high quality and healthy with no environmental cost, the cost of non-chemical alternatives will be similar to, or lower than, chemical alternatives.



## GRAFTING AS A NON-CHEMICAL ALTERNATIVE TO METHYL BROMIDE FOR TOMATOES IN SPAIN

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### ABSTRACT

Grafted tomato has been known for a long time but has only recently been expanded into cultivars of *Cherry* and *Marmande* types as a way of protecting against soil-borne diseases or against 'collapse', a non-well known disease typical of winter-producing tomato crops. Grafted tomato plants provided resistance to vascular diseases (*Fusarium* and *Verticilium*), and nematodes, even in varieties that have no resistance. Grafting onto interspecific rootstocks (*L. esculentum* x *L. hirsutum*) improved plant vigour and led to crop two-branch plants. The same yields were obtained with half the plant density, and moreover, without reducing the quality of the fruit. Grafted tomato can therefore be considered an alternative to the use of methyl bromide for tomato production in Spain.

**Keywords:** tomato, grafted, *Fusarium*, *Verticilium*, methyl bromide, alternative

### INTRODUCTION

Grafted watermelon, using rootstocks resistant to soil-borne diseases, has expanded considerably in Spain over the past 10 years. Nowadays, it is hard to find ungrafted plants in the most important production areas, both in greenhouses and in the open air. Grafting is a non-polluting technique. Grafting onto cucurbit rootstocks (*Cucurbita maxima* x *Cucurbita moschata*) improved the vigour of watermelon plants, made them completely resistant to *Fusarium oxysporum* f. sp. *niveum* and tolerant to a broad range of pathogens. As a consequence of the yield and production security obtained using grafted plants, grafting in watermelon has proved cost-effective and eliminated the need for soil disinfection with methyl bromide (MB) even before its prohibition.

In melon, grafting makes plants resistant to *Fusarium oxysporum* f. sp. *melonis* and to *Melon Necrotic Spot Virus* (MNSV). The usual rootstocks are also tolerant to *Monosporascus cannonballus*. There are some affinity problems with Spanish-type cultivars and an increase in fruit size in other cultivars of *Galia* and *Cantaloup* types. These problems have slowed the expansion of this technique in melon production.

In tomato, grafting has been known for a long time but it has only recently been expanded into cultivars of *Cherry* and *Marmande* types as a way of protecting against soil-borne diseases or against 'collapse', a non-well known disease typical of winter-producing tomato crops.

### COMPARISON OF ROOTSTOCKS IN DIFFERENT TOMATO CULTIVARS

Two experiments were carried out in Alginet (Valencia, Spain) in a tunnel covered with anti-thrips net, and in Paiporta (Valencia, Spain), in a greenhouse covered with both anti-thrips net and plastic film. Tomatoes were planted on 4 August 2000 and 26 January 2001 respectively.

The same rootstocks were used in both experiments: 'Brigeor' (*Lycopersicon esculentum* x *Lycopersicon hirsutum*) (KNVF<sub>2</sub>Fr) and 'SC-6301' (*Lycopersicon esculentum*) (NVF<sub>2</sub>Fr). In Alginet, the cultivars 'Valenciano' and 'Bond' (VF<sub>2</sub>N) were used. In Paiporta, 'Bond' (VF<sub>2</sub>N) and 'Raf' (F) were used.

In Alginet, the highest yields were obtained in grafted plants of both cultivars, although the differences between those and control plants were only significant in plants grafted on 'SC-6301'. Yields were also significantly (99%) higher in plants of 'Bond' than in plants of 'Valenciano'. At the end of the crop, 40% of ungrafted 'Valenciano' plants had died, with the root system

destroyed or severely damaged by nematodes, while all grafted plants of the same cultivar and either grafted or ungrafted plants of cultivar 'Bond' were alive.

Table 1: Total tomato yield and mortality of plants. Alginet 2000.

Root stock	YIELD (Kg/m <sup>2</sup> )			DEAD PLANTS (%)	
	Bond	Valenciano	Average	Bond	Valenciano
Brigeor	6.22	4.27	5.25 ab	0	0
SC-6301	6.37	5.08	5.72 a	0	0
Non grafted	5.50	3.17	4.33 b	0	40
	6.03 a	4.17 b			

Similar results were observed in Paiporta. Both cultivars ('Raf' and 'Bond') grafted onto both rootstocks or ungrafted plants of 'Bond', were resistant to nematodes and produced higher yields than ungrafted plants of 'Raf'.

Table 1: Total tomato yield and root-knot index. Paiporta 2001.

Rootstock	YIELD (Kg/m <sup>2</sup> )			ROOT-KNOT INDEX		
	RAF	Bond	Average	RAF	Bond	Average
Brigeor	11.95	16.61	14.28	0.71	0.75	0.73
SC-6301	11.24	14.66	12.95	0.50	0.25	0.37
Non grafted	4.70	15.80	10.25	3.91	1.41	2.66
	9.97 b	15.35 a		1.71	0.80	

### COMPARISON OF PLANT DENSITIES AND TRAINING METHODS USING GRAFTED TOMATO PLANTS

This experiment was conducted in Paiporta. Plants of cultivar 'Raf' grafted onto the rootstock 'Brigeor' were planted on 26 January 2001 in a greenhouse covered with anti-thrips net and plastic film. Two branch densities were compared, obtained as follows: 2.86 branches/m<sup>2</sup>; 2.86 plants/m<sup>2</sup>, 1 branch/plant; 1.43 plants/m<sup>2</sup>, 2 branch/plant; 2.29 branches/m<sup>2</sup>; 2.29 plants/m<sup>2</sup>, 1 branch/plant; and 1.14 plant /m<sup>2</sup>, 2 branch/plant.

In this experiment, no significant differences were observed between plant densities or training methods, and therefore it was possible to obtain the same yields both reducing plant density and training plants in two branches.

TABLE 3. Tomato yield (Kg/m<sup>2</sup> and Kg/plant) with different plant densities and training methods. Paiporta 2001.

	Kg/m <sup>2</sup>			Kg/plant		
	One branch per plant	Two branches per plant	Average	One branch per plant	Two branches per plant	Average
2.86 branches/m <sup>2</sup>	16.61	15.93	16.27	5.81	11.15	8.48
2.29 branches/m <sup>2</sup>	14.98	13.80	14.39	6.55	12.08	9.31
	15.79 a	14.86 a		6.18	11.61	

### CONCLUSIONS

Grafted tomato plants provided resistance to vascular diseases (*Fusarium* and *Verticillium*), and nematodes, even in those varieties that have no resistance. Grafting onto interspecific rootstocks (*L. esculentum* x *L. hirsutum*) improved plant vigour and led to crop two-branch plants. The same yields were obtained with half the plant density, and moreover, without reducing the quality of the fruit.

## THE ECONOMIC IMPACT OF THE PHASE OUT OF METHYL BROMIDE ON HORTICULTURAL PRODUCERS IN HUNGARY

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### ABSTRACT

Horticulture and mainly vegetable growing is a very important sector of the Hungarian Agriculture especially if export is considered. MB is used against soil borne pathogens, mainly nematodes under glasshouses and heated plastic tunnels, and in few cases under non heated plastic tunnels for vegetable growing. It has been registered since the mid 1980's. The tobacco industry was also using MB until 1999 when they converted to floating bed technology and phased out their use of MB. The future for protected vegetable production, the use of MB and preparations for eliminating its use are described.

**Keywords:** economic impact, phase out, geothermal energy, Hungary.

### INTRODUCTION

Árpád Co is one of the top Hungarian agriculture companies. Árpád as a Vegetable Growing Co-operative was founded in 1960. It was first involved with open-air crops and later with crops grown under glass and plastic. Today Árpád is no longer a Coop because of political and economical reasons. The company changed to an Incorporated Share Company in 1999, with a founding capital of 3 Billion HUF which is about US\$10 million.

Szentes and the surrounding area has a tradition in vegetable production going back for centuries. Gardeners from the present Bulgaria immigrated to Hungary in 18th century and established a new method of vegetable production with intensive irrigation between the rows. They also brought with them their new types of vegetables not grown in Hungary before. These gardeners delivered their products not only in towns in Hungary but deliveries went as far as Vienna.

The region has good soil quality. From the rivers and irrigation canals in the nearby good quality water could be gained for irrigation. There are more than 2 050 sunshine hours each year. A special condition of the area is geothermal energy. The vegetables have been grown under glass and plastic for the past 30-40 years. Wells were drilled and the thermal energy was used for heating greenhouses which has made large scale vegetable production under glass and plastic profitable. Árpád uses 14 thermal wells (average depth 2 000 m, temperature 78-96°C yield 60-70 m<sup>3</sup>/hours) to heat 46 hectares of glasshouses and plastic tunnels as well as animal farms, a grain drier and social buildings. This is the world's largest agro-project use only geothermal energy.

### PRODUCTION AND MARKETING

More than 500 families are growing vegetables – with the technical assistance of Árpád's engineers - under 23 ha glasshouses under 23 ha heated plastic tunnels, under 40 ha non heated plastic tunnels and on 50 ha open air. The total amount produced is around 10 000 tons a year and the turnover is 1,8 Billion Ft (more than 6 Million US\$).

The most important product for Árpád is the white-yellow sweet paprika (cone shaped). The varieties are mainly Hungarian hybrids. This paprika is grown and sold each day of the year from January till December. It is produced under glass, under heated plastic, and under non-heated plastic tunnels.

The next important crop is the tomato which is grown under glass (spring and autumn) and under heated plastic tunnels. The varieties are different Dutch varieties. On smaller acreages, Árpád produces in glasshouses hot green paprika (pepperoni) and cucumber.

The typical main crop under non-heated plastic is the yellow sweet paprika. As early spring crops Chinese cabbage and other Brassicas are in our product range, with a harvest in April, May. On open air (partly covered by flies plastic layer) we also produce Chinese cabbage and other Brassicas, Onion, Spice Paprika for milling. Árpád has well-trained effective plant protection and production technology. An Advisory Service Team helps Árpád to integrate the small individual growers. Altogether some 1 500-2 000 small producers are integrated in this way.

We also have coolhouses where products are stored. Árpád prepares the products for shipment for the home market or to abroad. One of Árpád's coolhouse complexes was modernised in 2000 which is now according the newest EC standard environment friendly. From our total turnover mentioned above about 30-40 % is going to export (+ 2 Million US\$/year), and 60-70% for the home market.

The custom yard of Szentes is working at this modernised coolhouse where not only the products of ÁRPÁD, but products of other companies of the town are cleared. The products of our company and products sold through the integration are well known in Germany, in Scandinavian countries, in Slovenia, Slovakia, in Chech Republic and in Austria.

### **CERTIFICATION PROGRAMMES**

The Company Det Norske Veritas certified our vegetable production and sales according the ISO 9002 Standard in 1998. HACCP certification is also under preparation (for Chinese cabbage and paprika it has been completed). We also started the ISO 14000 Standard for horticulture production and sales.

As the customers abroad and also on the home market are more and more interested in healthy products, Árpád started an Integrated Pest Management Programme several years ago. Bumblebees are used for better pollination and beneficials are used to control the different harmful insects. Árpád is also a distributor with exclusive rights for a Belgian company in this field.

In 2000 the operation was so successful that no chemical treatment was needed at all in some of our glasshouses involved in the project. In 2001 the start was not as easy as too many insects survived the mild winter, so we were facing much more problems than in 2000, and we had to spray against trips, and other insects.

### **METHYL BROMIDE USE AND PHASE OUT**

As Árpád had fairly old production facilities (built in 1960's and 1970's) and the monoculture type of growing created more problems with soil born pests and diseases (especially nematodes and thrips), Árpád was one of the first companies in Hungary to obtain the right to use MB for disinfection of the soil of our greenhouses. Árpád and Zephyr Ltd are now the only importers of MB which was 27 tons in 2001.

As we became aware of the Montreal Protocol and the phase-out requirements, Árpád started to modernise its greenhouses for soilless rockwool technology. In 1998, a pilot glasshouse of 3 600 m<sup>2</sup> was prepared to grow tomato on rockwool. As the results were good we increased the field of tomato in 1999 to 1 ha. In 2000 paprika on rockwool was grown on 2 ha. Based on a successful project with the Ministry of the Netherlands Árpád made a big step in 2001 as another 4 ha of paprika on rockwool was started. In 2002 a further 4 ha investment was completed for 2 ha paprika, 1 ha tomato and 1 ha cucumber. For the time being, 11 ha rockwool is in production and we have our further efforts to increase this. Of course, the investment costs and support for modernising such an old operations have also been determined to meet the phase out of MB.

## **PROGRAMME WITH GRAFTED PLANTS**

Árpád considers grafted plants as a good solution for use in heated plastic tunnels. The heated plastic tunnel units in practice are too small, they have small air spaces, are having different heating possibilities and also problems with irrigation water quality (filtering needed). These conditions make growing plants on rockwool almost impossible. Grafted paprika plants solve some of these problems.

These grafted plants we buy from Italy. The root plant is Snooker the producing plants are the traditional varieties. The much stronger and bigger root mass is supplying the upper producing plants with more water and feed and minerals, and the stronger crop is more resistant to stress and to any diseases, viruses, bacterias etc.

Also the larger root is more tolerant to nematodes and consequently much larger leaf mass is developed and larger yields could be expected. To save costs, the bigger roots allow us to use two main stems if compared with the traditional growing technic where only the main stem is used.

The first trials we made in 2000 with grafted paprika culture under heated plastic were quite promising. Based on trial results today some of our colleagues decided to use under their private heated plastic tunnels grafted plants.

## **SOLUTIONS FOR NON-HEATED PLASTIC TUNNELS**

As we have the possibility to move to new land (move the tunnel to a new area), this could solve the problems related with soil born pests and diseases.

Other possibilities with alternative chemicals and growing technics we could rely on "The Regional Demonstration Project conducted in Poland". Also the grafted paprika growing technique combined with some chemical treatments could bring good results under non-heated plastic tunnels.

## **COMMUNICATION OF RESULTS OF PROGRAMMES**

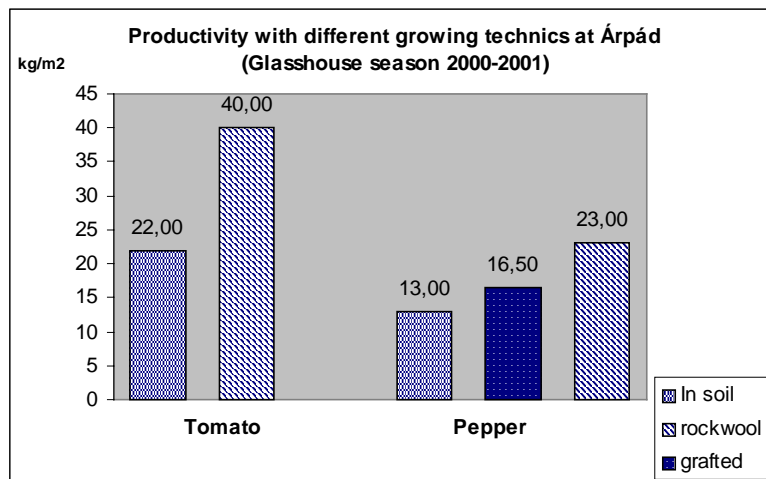
Árpád organised two workshop days (one in Spring one in Autumn) and invited growers from all over Hungary and specialists from abroad to make presentations. Last time we organised on 6th and 7th of April 2001 two very successful Workshop days (we call it "Day of the Open Gates") as we let the visitors to see everything. This time the subjects were: "Soilless paprika growing under greenhouses and the new technology with the grafted plants". Árpád also has its own newsletter which is sent to all growers involved in production. Árpád's specialists also write articles for the growers interest's and publish in periodicals such as "Horticulture and Vinary", "Plant protection", "Hungarian Agriculture". In addition to local growers, Árpád also receives groups that are participants from abroad taking part on congresses, seminars and workshops.

Table 1 and Figure 1 summarise the results of the new techniques. Of course, the operating costs are higher on rockwool and with grafted plants, but still bring a profit and a healthier product. Árpád calculates investments costs to be returned in a max. of 4-5 years. Investment costs include: Soil removal 5 000 m<sup>3</sup>/ha, in order to increase the possible height of the crop; change of old isolation, broken glass; new heating system; new drip irrigation system; new irrigation water cleaning system; new irrigation water distribution system.

**Table 1: Summary of economic impact comparison of yields, incomes of different cultures and growing methods (Glasshouse season 2000-2001)**

Data	Tomato		Pepper		
	In soil	rockwool	In soil	grafted	rockwool
Yield kg/m <sup>2</sup>	22 <sup>1</sup>	40	12-13 <sup>2</sup>	16,5	22-23
Income Ft/m <sup>2</sup>	3 800	6 000	2 800	3 700	6 000
Mbr cost Ft/m <sup>2</sup>	190	-	190	190	-
Investment costs Ft/m <sup>2</sup>	-	5 000	-	-	5 000

<sup>1</sup>Tomato in soil 2 crops spring and autumn. <sup>2</sup>One spring crop only



**Figure 1:** Productivity of tomato and pepper grown in soil, rockwool and grafted

*Árpád* sees in 2005 as the deadline for equipping all of its greenhouses with the rockwool growing technique thereby avoiding the need for MB or other chemical for soil disinfestation. By managing this great step *Árpád* hopes to create a healthier environment.

## NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USE IN JORDAN

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### ABSTRACT

Jordan consumes about 350 tonnes per year of methyl bromide (MB). This amount is used to fumigate the soils of plastic houses which are planted mainly with cucumber and tomato. The number of plastic houses in Jordan ranges from 30,000 to 35,000 in the irrigated areas.

Jordan has signed Montreal Protocol to phase out MB. Jordan, however, is trying to phase out MB by the year 2005. A research project was established to find out the suitable alternative(s) that could replace MB in protected agriculture in Jordan.

Two sites were chosen in different agro-climate zones. Alternatives such as soil steaming, biofumigation, soilless culture, and chemicals were tested. MB and control treatments were added. Six treatments were conducted in each plastic house with four replications.

Results showed that soil steaming and biofumigation alternatives had a positive effect on reducing soil pathogens, but control was less effective than MB. Total crop yield of cucumber under the three alternatives (steaming, biofumigation and basamid) was slightly lower than MB, and higher than control treatment in both sites. Soilless culture, however, may produce higher yield but the system requires more experience before it can be applied commercially.

**Keywords:** methyl bromide, soil steaming, soil biofumigation, root-knot nematode, *Fusarium*.

### INTRODUCTION

Methyl bromide (MB) is a broad-spectrum chemical commonly used as a soil fumigant to control of soil borne diseases, nematodes, insect pests and weeds. Between 30 and 85% of the total MB applied to the soil reaches eventually the atmosphere. It is now recognized that MB contributes significantly to ozone depletion and was listed as an ozone-depleting substance (ODS) by the Parties to the Montreal Protocol in 1992 (UNEP 2001). The development of a comparable agricultural system without the use of MB, in many cases, will require extensive research to achieve a similar spectrum of efficacy and reliability.

The horticulture sub-sector in Jordan is being subjected to high intensification using the latest technology. Jordan is considered as a big producer and exporter of vegetable crops to the neighboring states.

Actually the total consumption of MB in Jordan for soil fumigation is estimated to be c. 350 tonnes per year. It is used to sterilize seedbeds in nurseries and for plastic house vegetable production (tomato, cucumber, sweet pepper, strawberry). Up to 97% of MB used in Jordan is applied in the Jordan Valley. The majority of the farmers (82%) apply MB once a year. The total treated area can be estimated by 43% of the total area of plastic houses in Jordan.

Root knot nematodes are important phytopathogenic nematodes causing large economic losses. The species *Meloidogyne incognita* and *M. javanica* are present with a differential distribution of species. *M. javanica* is mainly present in the areas with higher temperatures found in the southern Jordan Valley, whereas both species are present under more temperate climatic conditions of the middle and northern Jordan Valley. Fungal diseases, however, include *Fusarium oxysporum*, *F. solani*, *Pythium* spp. *Sclerotinia* spp. and *Verticillium* spp. A synergistic effect between root knot nematodes and *Verticillium* wilt has been observed.

Non-chemical alternatives such as solarization, biofumigation, soil steaming and soilless culture are recognized as effective alternatives. The main objective of this study is to determine the suitable alternative(s) that could replace MB use in the protected agriculture in Jordan.



## MATERIALS AND METHODS

Cucumber crop was chosen to test different alternatives to the use of MB. Cucumber accounts for 48% of MB usage in Jordan. The sites were selected according to their differential agro-ecologic characteristics, as well as actual and potential use of MB.

The experimental sites were located in Deiralla area (Middle Jordan Valley) and irrigated Uplands. The chosen areas accounted for 53% of the total MB use. Both sites were approved after conducting several laboratory tests for many farms in order to find contaminated farms with soil borne diseases (nematodes and fungi). Both sites were intensively cultivated in the past five years. Drip irrigation and black plastic mulch to control weeds are common practices at both sites.

The middle Jordan Valley site elevation is 224 m below sea level. Soil type was classified as silty clay (clay 46%, sand 13%, silt 41%). Soil pH ranged from 7.9 to 8.2 and soil EC ranged between 3.7 and 5.2 dS/m. Water pH was 7.8 and EC was 2.0 dS/m. Date of planting was on 20 December 2000.

The Upland site elevation is 720m above the sea level. The soil type was classified as clay soil (74.9%). Soil pH ranged between 7.2 and 8.3 and soil EC ranged between 1.8 and 4.9dS/m. The field was irrigated from the under ground water where water pH was 7.4 and EC was 0.9 dS/m. Date of planting for the Upland site was 22 April 2001.

Four different alternatives (Biofumigation, Soil Steaming, Soilless culture and Basamid) were chosen for each site. These alternatives were compared with MB treated and untreated plots (control).

Biofumigation treatment was applied by adding fresh manure ( $7 \text{ kg/m}^2$ ) to the soil surface and well mixed then the plots were watered. The plots were covered by plastic sheets (200  $\mu$  thick) for 15-30 days. After the plastic sheets were removed, the soil was ploughed, levelled and biocont (*Trichoderma*) added in an average of  $7 \text{ g/m}^2$  and (*Peacillomyces*) was added in an average of  $2 \text{ g/m}^2$  immediately before planting (Jatala 1986, Kabana and Morgan 1987). Data logger was used to determine soil temperature at different depths.

Soil steaming treatment was applied when the plots were leveled. The plots were covered by heat tolerant plastic sheet and soil surface was steamed until the soil temperature reached  $70 - 90^\circ\text{C}$  at 20 cm depth. The soil was aerated and biocont (*Trichoderma*) was added in an average of  $7 \text{ g/m}^2$  and  $2 \text{ g/m}^2$  *Peacillomyces* immediately before planting.

Soilless culture treatment was applied to six rows 9 m long and 0.4 m wide together with plastic sheets 1000 microns thick added to each plot. Rows were filled with tuff media in three layers (5cm of 10-20 mm particle size, 10 cm of 4-8 mm, and 5 cm of 0-4 mm particle size). Nutrient solutions were added by fertigation system.

The plots of chemical treatment (Basamid G) were cultivated and flooded by water in order to encourage weed growth. The soil then was ploughed, leveled and Basamid was uniformly broadcasted at an average of  $50 \text{ g/m}^2$  and mixed well with 10-15 cm of the soil surface when soil moisture was about 40% of the field capacity. The plots were then irrigated and covered with plastic sheet (200 microns thick). The plastic sheets were removed after three weeks of application to allow soil ventilation for four days before planting.

Five soil samples from each plot were taken randomly. The soil samples were taken from the top 30 cm. The samples were thoroughly mixed and a composite sample was prepared. The type and number of fungal propagules were determined by soil dilution methods. The type and number of plant parasitic nematodes were determined according to the modified Baemann funnel method.

Four plastic houses (9 X 56 m) with complete fertigation systems were installed at each site. Each plastic house contained one replicate. The experimental design was completely randomized blocks with six treatments in each plastic house.

## RESULTS AND DISCUSSION

Control percentage of both *Fusarium* and free-living nematodes was higher using MB and soil steaming treatments immediately after application in both sites. On the other hand, biofumigation treatment after application showed better control for free-living nematodes than *Fusarium*, especially in the Upland site (Tables 1 & 2).

However, developing *Fusarium* and second stage nematodes with periods of cucumber growth showed higher control with MB for both diseases in both sites (Table 3 & 4). Soil steaming showed better negative effect on *Fusarium* with time than on second stage nematodes in both sites. Whereas, biofumigation showed better effect on second stage nematodes than on *Fusarium* in both sites. The action of microorganisms on the manure during its decomposition produce substances such as ammonia, nitrate, hydrogen sulfide and a great number of volatile compounds and organic acids that are effective in controlling soil pathogens. Average soil temperature at 20 cm depth in the period of biofumigation treatment ranged from 5.9 to 8.6°C higher than the soil temperature of the control treatment at the same depth in both sites. This may provide a reason for the increase in soil temperature was not high enough to control *Fusarium* (Brid 1972).

Average plant fresh weight was lower under chemical and control treatments in both sites (Table 5). However, total cucumber yields under the three alternatives (biofumigation, soil steaming and basamid) were slightly lower than MB and higher than control treatment in both sites (Table 5). Soilless culture treatment may produce higher yield but it requires more experience to apply and monitor the system.

This preliminary study suggests that soil steaming, biofumigation and soilless culture are potential non-chemical alternatives to MB fumigation for soil pathogen control. Developed soilless culture technique may need further experience to be accumulated by farmers before it can be adopted.

TABLE 1: Average number of *Fusarium* (propagules/gm oven dry soil) before and after treatment application in Jordan Valley and Upland sites.

Treatment	Jordan Valley			Upland		
	Before	After	Control %	Before	After	Control %
MB	89.5	0.0	100.0	103.3	33.0	68.0
Biofumigation	102.0	52.3	49.0	110.0	70.8	35.6
Basamid	63.8	54.8	14.0	98.8	47.0	52.4
Soil Steaming	75.5	4.3	94.0	128.3	20.0	84.4

Soil steaming technology, however, may be applied via contract services. In conclusion, these results show that there are non-chemical alternatives to MB fumigation for Jordan vegetables. Farmers will ultimately determine which of these alternatives are feasible for their individual operations.

TABLE 2: Average number of soil borne free-living nematodes (*Rhadditis*/100cm<sup>3</sup> soil) before and after treatment application in Jordan Valley and Up-land sites.

Treatment	Jordan Valley			Upland		
	Before	After	Control %	Before	After	Control %
MB	241.5	0.0	100.0	1325.0	154.0	88.4

Biofumigation	192.5	92.8	51.7	1259.3	339.5	73.0
Basamid	187.3	22.8	87.8	1087.5	175.0	83.9
Soil Steaming	126.0	19.3	84.7	1022.5	56.0	94.5

TABLE 3: Average number of *Fusarium* (propagules/gm oven dry soil) with periods of plant growth (days) in Jordan Valley and Upland sites.

Treatment	Jordan Valley			Upland			
	25 d	90 d	140 d	25 d	65 d	103 d	135 d
MB	0.0 b	28.5 c	56.5 c	33.0 bc	14.0 b	70.8 c	62.5 c
Biofumigation	52.3 a	150.0 a	93.5 a	70.8 a	15.0 b	118.0 ab	92.0 b
Basamid	54.8 a	51.5 b	61.5 b	47.0 b	40.0 a	135.8 a	131.0 a
Soil Steaming	4.3 b	40.3 bc	64.0 b	20.0 c	0.0 c	95.5 bc	78.0 c

TABLE 4: Average number of second stage nematodes (*Meloidogyne*/100 cm<sup>3</sup> soil) with periods of plant growth (days) in Jordan Valley and Upland sites.

Treatment	Jordan Valley			Upland			
	25 d	90 d	140 d	25 d	65 d	103 d	135 d
MB	0.0	0.0	0.0 d	0.0	0.0	0.8 c	2.5 c
Biofumigation	0.0	0.0	0.6 c	0.0	0.0	21.0 b	31.5 bc
Basamid	0.0	0.0	57.8 a	0.0	0.0	29.8 a	77.0 a
Soil Steaming	0.0	0.0	17.7 b	0.0	0.0	33.3 a	44.8 b

TABLE 5: Total cucumber yield (kg/plant) and plant fresh weight (g/plant) at experiment termination in Jordan Valley and Upland sites.

Treatment	Jordan Valley		Upland	
	Fruit Yield (kg)	Plant Fwt (g)	Fruit Yield (kg)	Plant Fwt (g)
MB	4.38 ab	703.1 a	4.13 a	1150.0 a
Biofumigation	3.69 bc	537.5 b	4.11 a	975.0 b
Basamid	3.69 bc	503.3 c	3.78 bc	931.3 bc
Soil Steaming	3.96 b	581.3 b	4.15 a	1162.5 a
Soilless Culture	5.32 a	-----	3.82 b	-----
Control	3.44 c	503.1 c	3.60 c	831.3 c

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## NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USED IN GREECE ON HORTICULTURAL CROPS

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### ABSTRACT

Extensive research on solarization in Greece was shown to be effective in reducing diseases of vegetables and increasing yield. tomato soilborne pathogens for two consecutive cropping seasons. Soil solarization for 3 weeks with impermeable plastics was efficient in almost nullifying the percentage of diseased tomato plants during the first cropping season and avoiding *Meloidogyne* infection. Solarization significantly inhibited root infection by *Meloidogyne* in the second cropping season indicating a long-term effect of solarisation. Reduced duration solarization using impermeable plastics could be a valuable alternative to methyl bromide fumigation in Greece. Research should continue to assess a combination of antagonistic organisms with soil solarization. It is possible that duration of solarization could be further reduced if properly combined with tolerant or resistant rootstocks against several diseases of vegetables.

### INTRODUCTION

Vegetable cultivation in Greece has been based on methyl bromide (MB) fumigation for several years. In parallel, the Greek climate favours application of soil solarization as a MB alternative for controlling soilborne pathogens of vegetables. Experiments on soil solarization for the last 25 years in Greece were effective in restricting diseases and increasing yield with a drastic reduction in the density of fungal propagules in vegetables. Although classical soil solarization is effective, its extensive commercialization as a non-chemical alternative has been rather restricted in certain regions of Greece.

The main soilborne pathogens of tomato cultivation in Greece are *Pyrenochaeta lycopersici*, *Fusarium oxysporum* f.sp. *radicis lycopersici*, *Verticillium dahliae*, *Phytophthora* sp. and *Clavibacter michiganensis* subsp. *michiganensis*. Furthermore *Meloidogyne* sp. is becoming a limiting factor particularly for summer plantations. Similarly soilborne pathogens including *Verticillium dahliae* and *Fusarium oxysporum* are also limiting factors for out of season cucumber, melon and watermelon cultivation. Artichokes, eggplants strawberries and peppers are also suffering from serious soilborne pathogens such as *Verticillium dahliae*.

### RESULTS

Short-term soil solarization using impermeable plastics (polyamide plastic sheets covered with polyethylene) seems to be a good approach in convincing the farmers to apply solarization. This was first demonstrated by using short-term soil solarization and biocontrol agents against *Fusarium oxysporum* f. sp. *cucumerinum*, *Fusarium oxysporum* f. sp. *radicis-cucumerinum* of cucumbers, and *Fusarium oxysporum* f. sp. *niveum* of watermelons.

Experimental trials were recently carried out to control the main tomato soilborne pathogens for two consecutive cropping seasons. Soil solarization with impermeable plastics was efficient in almost nullifying the percentage of diseased plants during the first cropping season (winter-spring). No difference among 3 and 4 weeks solarization was observed, proving that 3 weeks solarization was more than enough when impermeable plastics were used. No *Meloidogyne* infection was observed. During the second cropping season during summer-autumn, all treatments significantly inhibited root infection by *Meloidogyne* indicating a long-term effect of the method.

## CONCLUSIONS

It seems that reduced duration of solarization using impermeable plastics could be a valuable alternative to MB fumigation in Greece. Research should continue to assess a combination of antagonistic organisms with soil solarization. It is possible that duration of solarization could be further reduced if properly combined with tolerant or resistant rootstocks against several diseases of vegetables. Melons, watermelons and cucumbers are suffering from Fusarium wilts and resistant rootstocks are available against these pathogens. However, resistance against other soilborne pathogens such as *Verticillium dahliae* is not available. Therefore, combination with solarization is a recommended alternative.

More recently work on biofumigation in controlling Fusarium wilt of Asparagus was also initiated in asparagus plantations in northern Greece.

Solarization could also be applied in nurseries prior to young tree establishment to avoid infection by soilborne pathogens. Individual soil solarization was applied in the past against Verticillium wilt in existing olive, pistachio nut and almond orchards.

## NON-CHEMICAL ALTERNATIVES TO METHYL BROMIDE USED IN MACEDONIA ON VEGETABLES

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### ABSTRACT

The Republic of Macedonia produces a wide range of vegetables, the most important being tomatoes, peppers, cucumbers, cabbage, watermelons and melons. Greenhouse vegetable production is important for the export of fresh vegetables such as tomatoes and cucumbers. The reported use of MB in Macedonia in 1999 was 21.0 tonnes of which around 10% was used in vegetable production. In trials using MB, biofumigation + solarisation and dazomet, all treatments reduced rootknot nematodes and the indicator pathogen *Fusarium* to acceptable levels. Solarisation + biofumigation gave the best tomato yields of 126 tonnes. In the trials where cucumber was grown as the second vegetable crop, solarisation + biofumigation again gave the highest yield of 235 tons/hectare. MB treatment was the most costly at \$65,280/ hectare for tomato and \$42,248 for cucumbers, compared to \$59,514 and \$41,516 respectively for solarisation + biofumigation. The market price of the tomatoes was the same for all treatments but increased profitability using the alternative was largely due to higher yield and lower production cost.

**Keywords:** tomato, cucumber, methyl bromide, alternatives, solarisation, biofumigation, dazomet, rootknot nematode, *Fusarium*

### INTRODUCTION

Production of vegetables has a special significance in the agriculture of the Republic of Macedonia. The suitable climate offered by the area enables the production of a wide range of vegetables, the most important being tomatoes, peppers, cucumbers, cabbage, watermelons and melons. Vegetables are produced on a total area of 56,000 hectares. Approximately 200-250 ha of production is in heated glasshouses. Greenhouse vegetable production is important for the export of fresh vegetables such as tomatoes and cucumbers, although greenhouses comprise only 0.2 % of the total arable land. Greenhouse cropping is considered to be a profitable activity provided it is reshaped to cope with market changes and other transformations of the region. The export – import of vegetables is highly successful, mainly due to greenhouse production.

The total production from greenhouses is about 19,000 tonnes. Two production cycles are practised per year so that crops are ready for harvest when market prices are highest. The first cycle starts in mid-January (or in February to avoid high fuel costs) and ends in mid to end June, or later. The second cycle starts at the end of July and finishes in November or December. The typical yield of tomato ranges from 100 to 130 tons per hectare, while cucumber yields are in the range of 160-200 t/ha.

The use of methyl bromide (MB) is limited to tobacco seedbeds. The reported use of MB in 1999 was 21.0 tonnes. A survey carried out by the Faculty of Agriculture during 2000 indicated that the real use of MB was probably twice that figure. Around 10% are used in vegetable production. From 1994 the use of MB in horticulture was banned. For that reason horticulture does not use large 50 litre cylinders of MB, but the small 454 ml cans permitted for tobacco seedbeds.

MB can be used for common soil-borne problems such as the following: weed control; damping off (*Phytophthora*, *Pythium* and *Rhizoctonia*); fusarium wilt (*Fusarium oxysporum*); verticillium wilt (*Verticillium dahliae*); bacterial canker (*Corynebacterium* spp.); alternaria stem canker (*Alternaria alternata*); late blight (*Phytophthora infestans*); root knot nematodes (*Meloidogyne* spp.)

## METHODS

Biofumigation combined with solarisation consists of mixing moist soil with organic matter and heating it by covering with a transparent plastic sheet. The soil temperature increases to a level that is lethal to many soil-borne pests and diseases. At the same time, the raised temperature favours the fermentation of the organic matter, generating gases that are trapped beneath the plastic and lethal to many undesirable microorganisms in the soil. The addition of organic matter reduces the time required for solarisation.

Cow manure at a concentration of 5-7 kg/m<sup>2</sup> is well distributed and incorporated into the soil to 20 cm depth. The soil is then irrigated with 30 mm of water, which should enable intensive decomposition of the manure and covered with transparent polyethylene. The process of decomposition is considered to be finished when the temperature starts decreasing down to 25°C. In the Macedonian climatic conditions (summer time) it takes two weeks to complete this procedure. However, it was found that when temperatures are not sufficiently high cow manure can introduce weed seeds, so it preferable to consider other organic sources of isothiocyanates, such as plant residues from the cabbage family.

## RESULTS AND DISCUSSION

A demonstration project on alternative to MB was carried out in Macedonia to compare MB, biofumigation + solarisation and Dazomet. All treatments reduced root knot nematodes and the indicator pathogen *Fusarium* to acceptable levels. The heat of solarisation controlled most pathogens in the upper 20 cm of soil. In the comparative trials, solarisation + biofumigation gave tomato yields of 126 tonnes, which was by far the highest of the three treatments. The control gave the lowest yield of 101 tons per hectare. In the trials where cucumber was grown as the second vegetable crop, solarisation + biofumigation again gave the highest yield of 235 tons/hectare. The results are shown in Table 1.

Table 1: Yield of greenhouse tomato and cucumber

Treatment	Average yield (tonnes/hectare)	
	Tomato	Cucumber
Control	101.4	158.8
Methyl bromide	114.0	202.0
Solarisation + biofumigation	126.0	235.6
Low doses of chemicals	113.0	222.2

In the case of tomatoes, production with MB was the most expensive method. The total production costs using MB were \$65,280/ hectare for tomato and \$42,248 for cucumbers, compared to \$59,514 and 41,516 respectively for solarisation + biofumigation. Likewise, MB was less profitable, giving gross profits of only \$48,720 her hectare compared to \$66,486 per hectare from solarisation + biofumigation in the case of tomato (Table 2). The market price of the tomatoes was the same for all treatments (about \$1 per kg). The increased profitability of the alternative was largely due to its higher yield, and partly due to its lower production cost.



Table 2: Cost of production and gross profit in greenhouse tomato and cucumber [US\$/ha]

Treatment	Total production cost	Gross income	Gross profit
<b>Tomato</b>			
Control	58,350	101,400	43,050
Methyl bromide	65,280	114,000	48,720
Solarisation + biofumigation	59,514	126,000	66,486
Low dose chemicals	62,148	113,000	50,852
<b>Cucumber</b>			
Control	39,023	95,280	56,257
Methyl bromide	42,248	121,200	78,952
Solarisation + biofumigation	41,516	141,360	99,844
Low dose chemicals	42,972	133,320	90,348

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