Replacing Methyl Bromide for Soil Disinfestation

The Italian Experience and Implications for Other Countries

Methyl bromide (MB) has been the most widely used chemical for the fumigation of soil, commodities, buildings, and furniture for over 70 years (5,57). Although MB consumption is still high as a soil and structural fumigant, its use is decreasing because of international regulatory measures designed to reduce substances that potentially deplete the stratospheric ozone layer (5,51).

The discovery of the role of bromine in the depletion phenomenon represented the turning point toward the elimination of MB as a fumigant.

The essential role of the ozone layer in shielding the planet from harmful ultraviolet solar radiation (UV-B) and the strong correlation between decreased stratospheric ozone and increased UV-B at the earth's surface have been documented. Increased surface UV-B has been correlated with increasing incidence of skin cancer, eye cataracts, immune-system deficiencies, and alteration of ocean ecosystems (52,61,68). Halocarbons (e.g., chlorofluorocarbons, halons, hydrochlorofluorocarbons, and carbon tetrachloride), used as propellants, refrigerants, and in fire extinguishers, were the first identified atmospheric pollutants that chemically react with ozone molecules to degrade the ozone layer. Once in the stratosphere, these compounds break down to form chlorine atoms that catalyze ozone destruction (46). Studies on the possible effects of MB on

ozone chemistry started in the 1970s, but the prevailing view at the time was that MB did not significantly deplete ozone in the stratosphere. However, by 1985, scientists found that bromine atoms were a major cause of ozone depletion. Bromine reacts with ozone in a manner similar to chlorine, but it is 50 times more reactive in depleting ozone because, in addition to destroying ozone molecules, it reacts with reservoir chlorine species, freeing the chlorine to react with additional ozone (3,50,67,70).

Unlike chlorine, which enters the stratosphere mostly from human activities, atmospheric bromine can result from both natural and anthropogenic sources. Determination of the relative magnitudes of natural and anthropogenic sources of MB led initially to much debate. It was concluded, with some uncertainties, that MB from human activities represents the larger source of bromine emission to the stratosphere. Among anthropogenic sources of MB, agricultural applications represent the largest (57,59).

The Montreal Protocol was adopted in 1987 by the international community with the aim to gradually phase out the production and use of ozone depleting substances (ODS) in an attempt to recover the ozone layer (48). In 1992, MB, when used as fumigant, was added to the list of ODS controlled by the Protocol. The agreement mandated a reduction in use of MB by industrialized nations to 1991 levels. Subsequently, the increase in depletion of the ozone layer and the urgency to adopt accelerated ODS phaseout schedules resulted in the adoption of more severe control measures on MB.

The MB phaseout under the Protocol has been modified several times, with the aim to accelerate the elimination of MB use both in industrialized and developing countries (Table 1). However, the economic and social significance of this fumigant in crop production was recognized by participants. The cultivation of many high-value crops in industrialized and developing countries had become totally dependent on the use of MB. At that time, MB had no obvious

Table 1. Control measures on methyl bromide (MB) production and consumption adopted by the meetings of the parties to the Montreal Protocol

Meetings of parties	Industrialized countries (Baseline: 1991)	Developing countries (Baseline: average 1995-1998)
4th (Copenhagen, 1992)	Freeze by 1995 ^y	...
7th (Vienna, 1995)	25% reduction by 2001 50% reduction by 2005 100% reduction by 2010 ^y	Freeze by 2002 ^y
9th (Montreal, 1997)	25% reduction by 1999 50% reduction by 2001 70% reduction by 2003 100% reduction by 2005 ^{y,z}	20% reduction by 2005 100% reduction by 2015 ^{y,z}

^y Quarantine and preshipment uses of MB exempted.

^z Possible exemption for critical uses.

Corresponding author: M. Lodovica Gullino, AGRINNOVA, Via Leonardo da Vinci, 44, 10095 Grugliasco, Italy.
E-mail: marialodovica.gullino@unito.it

replacement, and several available alternatives needed to be tested for efficacy in pest control and economic crop yields and quality. Lastly, the use of MB is an essential component of phytosanitary measures needed to prevent the introduction and establishment of exotic pests associated with imported and exported goods (31,48). In 1997, under the Montreal Amendment (9th Meeting of the Parties to the Montreal Protocol, September 1997), a final phase-out schedule for MB was agreed to. Industrialized countries would phase out MB by 2005, with 25, 50, and 70% reductions in 1999, 2001, and 2003, respectively. Developing countries would reduce production and use of MB by 20% in 2005 and totally phase out use by 2015 (Table 1). The developing countries were given a 10-year grace period due to social constraints and lack of alternate technologies.

Quarantine and preshipment uses of MB were exempted from control, while criteria were established for those specific uses of MB, qualified as "critical", where production and consumption of MB should be allowed after the phaseout date.

Global Use of MB

First commercialized in the 1920s for use in fire extinguishers on aircraft and ships, MB gained popularity as an agricultural fumigant in the 1960s. Its unique properties made MB the most desirable fumigant against insect and mite damage to seeds and harvested crops, and against soilborne pests (31,19). For example, MB is versatile and effective against a broad spectrum of pests. It penetrates to reach

pests in soil, commodities, and structures, and it is also effective at low temperatures. MB dissipates quickly after treatment, thus permitting rapid access to the fumigated areas.

The use of MB as a fumigant dramatically increased during the 1980s. Global use increased despite the high toxicity of MB and extensive investigations, carried out since 1970, of the potential risk of harmful residues of bromine or MB *per se* in crops (9) and groundwater (40,63). The results of such investigations have led to some regulation of use in northern Europe (64).

Of more than 60,000 metric tons of MB globally produced in 1991, about 87% was used in industrialized countries, including the United States (40%), the European Union (30%), and Japan (10%). Developing countries, including African (2.8%), and Latin American and Caribbean (2.5%) countries accounted for the remaining 13% of MB use (Fig. 1) (62). More than 80% of the global use of MB was for preplant soil fumigation for production of fruit and vegetables (45.7%), orchards and vineyards (22.4%), and nursery crops (12.1%). Fumigation treatment of structures and commodities accounted for 11.2 and 7.9% of MB use, respectively (Fig. 2) (51,68).

Restrictions of use of MB occurred only after its inclusion as an ODS under the Montreal Protocol in 1992. The regulatory restrictions of MB use adopted by the Protocol and the subsequent political and economic initiatives undertaken at national and regional levels have motivated research for MB alternatives. As alternatives

have been developed, industrialized countries have succeeded in complying with the Montreal Protocol requirements, reported under Table 1. By 2000, industrialized countries had moved beyond the 25% reduction targeted for 1999 and 2000, and some were close to a 50% reduction by 2001. The United States reduced MB usage from 25,500 metric tons in 1991 to around 11,000 metric tons in 2000 and accounted for 36% of global use in 2000. The European Union and Japan used approximately 7,700 and 4,273 metric tons, respectively, representing 25.6% and 14% of the 2000 global use (60,62). During the period 1991 to 2000, the use of MB continued, with the reduction indicated, on the same crops. Soil fumigation still represents the highest MB use, while commodities and structural fumigation continue to account for around 20% of global use. These data do not include quarantine and preshipment applications of MB, as exempted from control.

MB Use in Italy

Italy ranks first in Europe in horticultural crop production and accounts for 28% of European production of vegetables. Vegetable production is concentrated in southern Italy and is characterized by small-sized, highly specialized, and intensive cultivation systems with high plant densities and repeated plantings of the same crop. This type of production often leads to a buildup of plant pests in the soil. MB was quickly adopted as the primary means of soil disinfestation on high-value crops (19), and Italy soon became one of the largest global users of MB.

Fig. 1. World global methyl bromide use (metric tons) in 1991 (62).

The Italian situation reflects global MB use trends. In 1995, Italy used more than 7,600 metric tons of MB, ranking first in Europe and second in the world after the United States (23). Most MB is applied for preplant soil fumigation, mainly in southern Italy (89% of the total tonnage), including 56% in Sicily where horticultural production is more intensive. The highest uses of MB by crop are for tomatoes, strawberries, eggplant, and ornamentals (Fig. 3). Structural fumigation with MB represents only 6% of total use (Table 2) (6).

As a member of the European Union (EU), Italy had to comply with the MB

reduction targets defined by the European Regulations 3093/94 and 2037/2000 (Table 3), which are more severe than those defined under the Montreal Protocol (Table 1). At a national level, severe restrictions have been adopted for limiting the use of MB as a fumigant in the Lake Bracciano (central Italy) and Liguria regions (23), due to water contamination problems and the proximity to urban areas.

MB Alternatives

The global phaseout schedule adopted in 1997 under the Montreal Protocol provided renewed and stronger impetus to search for MB alternatives (32). However, finding

alternatives to MB that are both economically and environmentally acceptable in a relatively short time has not been an easy task. The evidence for this is perhaps most clearly demonstrated by action taken in the United States in 1998 to extend the domestic deadline for a complete ban on MB from 2001 to 2005. The change appeared to arise from increasing awareness that insufficient effective alternatives were available for the earlier phaseout (57).

What was true for the United States has been true for Italy and the other major users of MB. In addition, market forces have made research and field testing extremely urgent. Italy and other southern

Fig. 2. Distribution of global methyl bromide use among different applications during 1992 (51,68).

Fig. 3. Distribution by crop of methyl bromide used in Italy in 2001 for soil fumigation.

EU member states, including Greece and Spain, have been particularly concerned about whether competitors from developing countries in the Mediterranean might be able to gain a market advantage by being able to use MB with fewer restrictions (23,26,54). The same concern has been shared by other countries, including the United States, that can suffer from competition with Mexico (51).

The Italian Ministry of Environment and Territory, aware of the difficulties faced by Italian growers in meeting international regulations, supported research aimed at:

1. reducing the use of MB and its emission (short-term goal);
2. developing alternative pest control methods based on available technologies (mid-term goal);
3. developing new MB alternatives (mid- and long-term goal).

Reducing Use of MB and Its Emissions

In countries with significant MB dependence, such as Italy, the first step was to reduce application rates of MB. This was achieved with the development and use of virtually impermeable plastic films (VIF).

Previously, the most commonly used plastic films for MB fumigation were made of low-density polyethylene (LDPE) or high-density polyethylene (HDPE). These films are permeable to MB and allow its escape through the plastic sheet into the atmosphere within a short period after application. In contrast, films like VIF contain a layer of a barrier material such as polyamide or ethylene-vinyl alcohol and are significantly less permeable to MB (15). VIFs have an MB permeability rate of less than $1 \text{ g m}^{-2} \text{ h}^{-1}$. In contrast, the permeability rate for LDPE is greater than $50 \text{ g m}^{-2} \text{ h}^{-1}$. VIFs have similar physical properties, such as thickness and resistance to high temperature and mechanical stretching, to conventional LDPE films (16).

VIFs reduce the emissions of MB into the atmosphere because the MB concentration in the atmosphere trapped under the plastic sheet during the first minutes after fumigation is higher. Gas-tight films retain MB in soil for a longer period of time compared with standard LDPE and HDPE films, thus allowing more time for gas movement and improving its distribution in the soil profile. These factors permit the use of reduced dosages of MB while achieving the same pest control (43) (Table 4).

In Italy, for example, fumigation with MB at 30 g m^{-2} (half the recommended dosage) under VIFs has been effective in controlling major soilborne pests on many economically important crops and in a variety of situations including extremely high inoculum densities (29,41,43). These reduced-dosage treatments have also shown residual effects over at least two subsequent crops. By comparison, fumiga-

tion with MB at 30 or 40 g m^{-2} under LDPE films did not provide consistent and satisfactory disease control in soils infested with several *formae speciales* of *Fusarium oxysporum*, *Rhizoctonia solani*, *Pyrenochaeta lycopersici*, and *Sclerotinia* species.

A variety of VIFs have provided similar and satisfactory results under different situations in several countries, including France, Spain, Belgium, Israel, and the United States (8,14,15,16). After MB is banned, VIFs may find application in the so-called MB critical uses, further reducing MB emissions into the atmosphere.

Developing Alternative Pest Control Methods

Developing alternatives to MB use depends on a variety of factors, including

social infrastructure, climate, market conditions, pest presence, land availability, and soil type and conditions. The interactions of these factors require choices to be made on a case-by-case basis.

For instance, in the case of sweet basil, a minor crop very susceptible to many soil-borne pathogens and of high economic importance in the Liguria region, several options are possible. Growers replaced MB with soil solarization in the case of protected cultivation, and with steam in some glasshouses. Less frequently, in the case of the more sophisticated greenhouses, soil-less cultivation was adopted. In Sicily, on tomato, chloropicrin, registered in Italy in 2002, is quickly replacing MB. Chloropicrin is often used in combination with 1,3-dichloropropene. Moreover, whenever pos-

Table 2. Italian use of methyl bromide in 2001 (6)

Uses	Metric tons	%
Preplant soil fumigation	3,588	93.8
Commodities, products, and structures fumigation	236	6.2
Total	3,824	100.0

Table 3. Methyl bromide (MB) production and use phaseout schedules under the EU Regulations 3093/1994 and 2037/2000

EU regulation	Control measure ^x	
	Nonquarantine and preshipment	Quarantine and preshipment
3093/1994	Freeze on production and consumption by 1995 25% reduction by 1998	Exempted
2037/2000	25% reduction on production and consumption by 1999 60% reduction by 2001 75% reduction by 2003 100% reduction by 2005 ^z Mandatory application of VIF when MB is used for soil fumigation	Freeze on consumption by 2001 ^y ...

^x Baseline: production and consumption levels of 1991.

^y Baseline: average consumption levels of 1996-1998.

^z Possible exemption for critical uses.

Table 4. Efficacy of soil disinfestation with methyl bromide (MB) against *Rhizoctonia solani* when applied under different plastic films on two cultivars of basil (43)

MB (g/m ²) / plastic film	% of diseased plants at days after sowing			
	cv. Fine verde		cv. Genovese gigante	
Control	55	68	55	68
30 / LPDE ^x	28.3 c ^w	55.3 c	17.0 c	50.0 c
30 / VIF LMG ^y	7.7 b	15.3 b	5.7 b	7.3 b
30 / VIF PP ^z	1.7 ab	0.0 a	0.0 a	0.0 a
30 / VIF PP ^z	0.0 a	0.0 a	0.3 ab	0.0 a
60 / LPDE	0.0 a	0.0 a	0.0 a	0.0 a

^w Means in the same column followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).

^x Low density polyethylene film.

^y Virtually impermeable film obtained from Lawson Mardon Packaging (Ltd.) Group, Bristol, UK, multilayer gas-tight film 30 μm thick.

^z Multilayer gas-tight film 30 μm thick obtained from Plastopil Hazorea Kibbutz, Hazorea 30060 Israel.

Table 5. Characteristics of fumigants available for soil disinfestation compared with methyl bromide

Active ingredient	Formulation	Vapor pressure at 20°C (mmHg)	Boiling point (°C)	Active ingredient from degradation	Diffusion in soil	Biological activity
Methyl bromide (CH ₃ Br)	Liquid	1,420 (227 kPa at 25°C)	4	...	Very good	Fungicide, nematocide, herbicide
Dazomet (tetrahydro-3,5-dimethyl-2H-1,3,5-tiadiazine-2-tione)	Solid (liquid)	Negligible	...	MITC ^z , CS ₂	Low	Fungicide, herbicide (nematocide)
Metham-sodium (sodium N-methyl dithiocarbamate)	Liquid	20,7	...	MITC, CS ₂	Low	Fungicide, herbicide, (nematocide)
1,3-dichloropropene	Liquid	35 (3,7 kPa at 25°C)	104-114	...	Good	Nematocide
Methyl isothiocyanate	Liquid (solid)	13 (2,1 kPa at 25°C)	119	...	Low/good	Fungicide, herbicide, (nematocide)
Chloropicrin (trichloronitro-methane, CCl ₃ NO ₂)	Liquid	18,3	112	...	Good	Fungicide
Methyl iodide (CH ₃ I)	Liquid	400 at 25°C	42	...	Good	Fungicide, nematocide, herbicide

^z Methyl isothiocyanate.

Table 6. Efficacy of dazomet for control of *Rhizoctonia solani* on basil cv. Genovese gigante 45 days after sowing (45)

Dosage (g p.a./m ²)	Mulching period with polyethylene (days)	Diseased plants (%)
...	...	36.4 c ^z
25	...	34.1 c
50	...	22.8 b
25	7	1.4 a
50	7	7.1 a

^z Means in the same column followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).

sible, grafted tomato plants resistant to the most important soilborne pathogens are increasingly adopted, often in combination with 1,3-dichloropropene, and other crops are grown in rotation.

The different available alternatives to MB are listed below, with special reference to their application in Italy.

Chemicals. New fumigants with a broad spectrum of activity and with low environmental impact are not expected to be developed soon, and consequently growers have been forced to use existing compounds (Table 5). In Italy, there was a 16% increase in non-MB fumigant (mostly metham sodium and dazomet) use from 1993 to 1998 and then a decrease due to improved application methods and the use of nonchemical alternatives (1). Although no chemical provides an effective alternative to preplant uses of MB, other fumigants represent the first step in its replacement. Among those, methyl isothiocyanate and its generators (metham sodium and dazomet) are often considered as the most suitable short-term solutions, mostly due to their relatively low cost. However, they do not always provide complete disease control (42,45) (Table 6). Better results are achieved when they are applied under plastic films to minimize gas escape (28).

Chloropicrin was registered for use in Italy in 2002. When applied preplant by shank injection at rates equal to or greater

than 30 g m⁻², chloropicrin proved to be a viable alternative to MB. Chloropicrin provided acceptable disease control when tested against soilborne pathogens, including *Fusarium oxysporum* f. sp. *lycopersici*, *Verticillium dahliae*, *Pyrenochaeta lycopersici*, and *F. oxysporum* f. sp. *radicis-lycopersici* of tomato. However chloropicrin is slightly less effective than MB, particularly at low temperatures. Chloropicrin can be applied in the same cultural and environmental conditions as MB without requiring alternative application equipment or changes in crop production practices (Table 7) (27).

In contrast to MB, the effectiveness of chloropicrin is improved when the moisture content of soil infested with fungal propagules is high (47). This could explain the high efficacy of chloropicrin when applied by drip irrigation. The efficacy of chloropicrin against nematodes can be improved by mixing it with nematicides, such as 1,3-dichloropropene (10). Chloropicrin is expected to gain a significant portion of the fumigant market in Italy.

Sodium tetrathiocarbonate, registered as Enzone in some countries, degrades in the soil to release the broad-spectrum biocide carbon disulfide (CS₂) (69). It has shown inconsistent efficacy against soilborne fungi in Italy (A. Garibaldi, *personal communication*) and is not considered a reliable MB replacement candidate.

In the future, methyl iodide, a compound primarily tested in the United States as a fungicide and nematocide (49), could become available in Italy. However, concerns about the cost, potential toxic breakdown products in the soil, and ground water contamination still need to be addressed.

Other chemicals with more specific nematocidal activity, such as 1,3-dichloropropene, fenamiphos, and prophos, available in Italy as well as in other countries, are sometimes used (34).

In order to replace the many uses of MB, chemicals with more specific spectra of activity may need to be combined (53). Mixtures are far more complex to administer and regulate but should be considered as parts of integrated pest management systems.

Soil solarization. Largely exploited all over the world wherever the climatic conditions allow it, soil solarization has proven effective and reliable for soil pest control (33). It is particularly effective in reducing soilborne pathogens of vegetable and ornamental crops in greenhouse production in Italy (Fig. 4) (18,28,42). Although its efficacy has been extensively proven, soil solarization is still primarily limited to greenhouse production in Italy (19). The combination of shorter periods (2 weeks) of soil solarization with reduced application rates of fumigants such as dazomet or metham-sodium has been effective (21), and this may increase the number of growers who would consider using soil solarization. The use of half dosage of fumigant in combination with a shorter period of solarization is needed, at present, to achieve an acceptable level of disease control in some crops (22).

Host plant resistance. Varieties that are resistant or tolerant to one or more pathogens are available for many crops. Resistant hybrids with multiple resistance to several pathogens are currently used in vegetable production. This is particularly useful in the case of crops such as tomato,

Table 7. Effectiveness of chloropicrin (CP) and methyl bromide (MB) applied by soil injection for control of tomato diseases caused by *Pyrenochaeta lycopersici*, *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Fusarium oxysporum* f. sp. *lycopersici*, and *Verticillium dahliae* (27)

Application rate (g/m ²)	Infected plants (%)							
	<i>P. lycopersici</i>		<i>V. dahliae</i> + <i>F. oxysporum</i> f. sp. <i>lycopersici</i>		<i>F. oxysporum</i> f. sp. <i>radicis-lycopersici</i>		3 pathogens combined	
	PB ^x	V ^y	PB	V	PB	V	PB	V
Control, –	9.9 b ^z	14.9 c	4.3 b	5.3 a	22.5 b	25.5 b	36.7 b	45.7 b
CP, 20	0.0 a	0.0 a	0.5 a	2.7 a	5.9 a	3.5 a	6.4 a	6.2 a
CP, 30	1.6 a	0.0 a	0.5 a	1.7 a	5.2 a	7.5 a	7.3 a	9.2 a
CP, 40	4.3 ab	4.9 b	0.0 a	1.5 a	3.2 a	2.1 a	7.5 a	8.5 a
MB, 60	1.1 a	0.6 a	0.0 a	0.6 a	0.5 a	1.8 a	1.6 a	3.0 a

^x Principe Borghese.

^y Vulcano.

^z Means in the same column followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).

where varieties resistant to most soilborne pathogens are available (35). In most cases, new varieties are developed through traditional plant breeding techniques to address specific pest problems. Grafting susceptible crops onto resistant rootstocks is possible for several crops such as tomato hybrids resistant to *Verticillium* and *Fusarium* wilt and *Pyrenochaeta lycopersici*, cucumber (*Cucurbita vicifolia* as rootstock resistant to *Fusarium* wilts), and melon (*Benincasa cerifera* resistant to *Fusarium* wilt) (38). Grafting onto resistant rootstocks is popular in Asia and may also find application in Italy (22) because it can be combined with other control methods. Because of the high production costs and incompatibility to some environmental conditions, this practice is not commonly used (11).

Soilless cultivation. Soilless cultivation avoids the use of soil fumigation but requires proper disinfection of recirculating nutrient solutions. This method is gaining popularity in Italy, particularly for high-value crops such as rose, carnation, gerbera, daisy, basil, and lettuce (59). The disease problems of soilless cultivation systems (25,56) can be solved by adopting proper disinfection methods for the recirculating solution. In Italy and in Northern Europe, slow sand filtration has proven effective for water disinfection (20,66). The main constraints to the wide adoption of soilless cultivation in Italy are high initial investment costs and problems related to the disinfection, recycling, and disposal of recirculated solutions. Presently, only 500 ha of horticultural crops are in soilless cultivation in Italy.

Steam. New application technologies are under development which might significantly reduce the cost of steam soil disinfection (55). In Italy, steam is adopted in a few greenhouses for high-value ornamental crops (rose and gerbera) and vegetables (basil and spinach) (19). Among its positive features is its broad-spectrum of activity. The main constraints are its applicability only on small surfaces (benches, seedbeds, soilless cultivation, etc.), high cost, initial investment, energy

Fig. 4. Application of soil solarization inside a greenhouse.

consumption, and thus the contribution to the global warming process due to the use of fossil fuel.

Soil amendments. Organic and inorganic amendments (compost, manure, crop residues, etc.) can help control soilborne pathogens in vegetable and ornamental crops (30). The combination of amendments with solarization can also be effective.

When added to soil, amendments such as cruciferous residues and cow or poultry manure are subject to microbial degradation (glucosinolates breakdown, etc.) that results in the generation of biotoxic volatile compounds such as sulfur-containing compounds (isothiocyanates, ammonia, etc.), alcohols, aldehydes, and other volatile compounds. Such compounds can stimulate germination of fungal propagules and increase microbial antagonistic activity in soil, thus encouraging biological control. Microbial activity against pathogens in soil can weaken propagules during solarization or suppress their re-establishment in soil and plant roots after treatment. These effects have been observed for several soil-

borne fungi (*Verticillium* spp., *Rhizoctonia solani*, *Pythium* spp., *Sclerotium rolfsii*, etc.), nematodes, and many weeds (12,13,17,36,37,39,58). Several disadvantages (such as dependence upon environmental conditions, the nature and incidence of pathogens, and the type, consistency, and availability of the compost used) make it difficult to adopt these methods. In addition, the higher labor costs, the large amount of organic amendments required (50 to 70 tons ha⁻¹), and the possible release of phytotoxic compounds resulting in a longer waiting period between treatment and planting are limiting to practical application.

Biological and integrated control. Biocontrol agents active against soilborne pathogens, at present, prove effective only when applied in combination with other control measures. This has been clearly shown in the case of strains of *Trichoderma harzianum* and saprophytic *Fusarium oxysporum* (2,65).

There is wide agreement that a combination of different methods is needed to replace the use of MB in agriculture, since no single alternative is likely to provide

Table 8. Italian use (in metric tons) of methyl bromide (MB) in 2001 for soil fumigation by crop and region (6)

Crop	North	South	Sicily ^y	Total	%
Strawberry	162 (60) ^z	380 (100)	61	603 (160)	16.8 (4.6)
Strawberry nurseries	100 (100)	...	...	100 (100)	2.8 (2.8)
Tomato	15	270	1,230	1515	42.2
Pepper	...	90	200	290	8.1
Eggplant	...	50	250	300	8.4
Zucchini	...	...	47	47	1.3
Melon	7	80	170	257	7.2
Ornamentals	82	220 (150)	...	302 (150)	8.4 (4.2)
Others	20	100 (50)	54	174 (50)	4.8 (1.4)
TOTAL	386 (160)	1,190 (300)	2,012	3,588 (460)	100 (13)
%	10.8 (4.6)	33.2 (8.4)	56	100 (13)	

^y Sicily is considered apart due to its high use of MB.

^z Between brackets, use of MB only in open-field production.

Fig. 5. Mechanical application of virtually impermeable plastic films.

comparable control. It is very important to adopt IPM principles when implementing MB alternatives.

Developing New MB Alternatives

Long-term solutions for soil disinfestation will require heavy investment in research. For instance, methods for monitoring populations of soilborne pests and evaluating their impact should be developed. More innovative approaches in research concerning the microbiology of soils and substrates and ways to modify their composition, and the controlled introduction of beneficial microorganisms, are necessary (32). Effort should be made to avoid the widespread replacement of MB with other toxic chemicals, and some areas of research should be given priority. Basic research should investigate the modes of action of different control methods when used alone or in combination. For example, the weakening and delayed mortality of *Fusarium oxysporum* by sublethal heat treatments provided useful information on how to shorten solarization periods (4).

In order to make sure that new alternatives do not have undesirable side effects, long-term studies are needed. New technologies should be developed for improving, for instance, steam and chemical application.

Biocontrol agents, which at present play a very minor role in control of soilborne pathogens, could be used more effectively if their modes of action were fully understood (65).

Reduction in MB Use in Italy

Data collected in collaboration with grower and fumigation applicator associations showed a 50% reduction in MB use in Italy between 1995 (7,600 metric tons) and 2001 (3,700 metric tons). In Sicily during the same period, MB use dropped from 4,000 to approximately 2,000 metric tons even though the number of hectares in horticultural production remained the same (Table 8). This reduction was observed across all crops (6). MB reductions were the result of reduced MB application rates and adoption of new soil disinfestation techniques. These changes were imple-

mented by ad hoc teams of researchers and policy makers interacting with growers and their associations, fumigators, agrochemical industries, and extension agents. The number of Italian growers who have replaced MB with new alternative technologies has increased thanks to intensive research, training, and dissemination activities.

Introducing a new agricultural technology to farmers requires a coordinated effort to avoid failures and economic losses resulting from premature introduction (31). The introduction and acceptance of VIFs for soil fumigation represents an example of how new techniques were implemented in Italy. Initially, growers were not convinced of the value of VIFs. Demonstration trials were established on farms in collaboration with growers and fumigation companies. Based on grower input, the physical properties of the plastic films were improved by VIF manufacturers to resist stretching and tearing during application (41). Films were also sized to meet growers' needs. Technical seminars, meetings, workshops, and field days were conducted to demonstrate the effectiveness of VIF technology. Now VIFs are widely used on many crops such as strawberry, tomato, pepper, eggplant, basil, zucchini, melon, gerbera, rose, and bulb crops (Fig. 5). In 2001, over 2,500 ha were fumigated using the VIF technology, with a subsequent 50% reduction of MB.

Initially, VIFs were more expensive (0.1 Euro m⁻² VIF) than the traditional LDPE plastic films (0.05 Euro m⁻²), but these costs were eventually offset by savings from reduced application rates of MB. When MB is applied using the cold gas method, the cost of application (VIFs, gas, and labor) is approximately 0.40 Euro m⁻². Of this amount, 12.5% represents the cost for VIFs. If applied without VIFs, it would cost 0.6 Euro m⁻² for MB and labor. Considering the good results with VIFs to reduce MB dosages and emissions leading to lower fumigant consumption, Italian and European policy makers recognized the benefits of using VIFs and made them mandatory in October 2000 (European

Regulation EU 2037/2000) when MB is used for soil fumigation. VIF technology will remain useful for the application of other fumigants after the elimination of MB by 2005 (Fig. 6) (44).

The increasing use of other alternative fumigants such as chloropicrin, methamsodium, dazomet, and 1,3-dichloropropene (1) has been the result of cooperation between the agrochemical industry and researchers. Together they improved application methods and efficacy, making these older chemicals more acceptable to growers. For example, some industries helped speed registrations of 1,3-dichloropropene for protected crops and chloropicrin in Italy. Agrochemical industries supplied technical information and demonstrated soil fumigation techniques for these products. This approach not only provided growers with application expertise for MB alternatives, but opened new opportunities for companies affected by the MB phase-out (23,24).

The Future

The regulatory policies for MB use adopted under the Montreal Protocol and the subsequent political and economic initiatives undertaken at national and regional levels have motivated research for MB alternatives. The increasing availability of practical alternatives has resulted in a reduction of MB use for many of its former applications. Although the accelerated schedule has made the replacement of MB difficult, industrialized countries have succeeded in complying with the Montreal Protocol requirements.

Globally, there are potential alternatives for many applications of MB, but because many are less economical or practical, they are not being broadly implemented as long as MB continues to be available. However, as the date for phaseout approaches and the quantity of MB on the market drops, its cost can be expected to rise and users will be forced to switch to alternatives (57). Italy provides a good example. The cost of MB has increased by an average of 30% since 1991, and this has pushed Italian growers to switch to other fumigants. At the same time, there were improvements in application methods for the chemical alternatives, leading to reduced dosages and lower environmental impact and risk of worker exposure (22). Moreover, the adoption of nonchemical alternatives slowly but steadily increased as a result of the many activities (demonstration trials, seminars, etc.) carried out in the country.

The gradual shift to MB alternatives over a 10-year period, as well as the use of half rates of MB under VIFs, has generally prevented the much feared loss of competitiveness of Italian horticulture. Extension, in cooperation with the fumigation companies, was able to provide growers with a range of methods for soil disinfection.

Fig. 6. Application of chloropicrin by injection under virtually impermeable plastic film.

Developing countries have a later phase-out date, and their use of MB has increased by approximately 25% in the last 10 years. Countries in Asia and Latin American now represent 38% of total global consumption of MB (62). Bilateral and multilateral cooperation initiatives should be strengthened, and more human, financial, and technological resources should be channeled to reduce MB use in these countries.

The experience gained in industrialized countries can help developing countries define strategies and training programs needed to comply with the Montreal Protocol. This is currently being done in many cases, with special attention for countries such as China, where a strong increase in MB consumption is observed (7).

Acknowledgments

Work on this article was carried out in the frame of the agreement between AGRINNOVA of the University of Torino and the Italian Ministry of Environment and Territory titled: "Crop protection in the respect of the environment". We thank the many coworkers and students who cooperated during this project. Thanks are also due to the growers' associations and the fumigation companies that have participated in the collection of data on methyl bromide consumption. We thank Prof. Jaacov Katan and Dr. Charles J. Delp for critically reviewing the manuscript. Moreover, the useful comments and suggestions by Dr. Ned Tisserat and by the anonymous referees are kindly recognized.

Literature Cited

1. Agrofarma. 2001. Prodotti Fitosanitari in Agricoltura: Andamento e previsioni.
2. Albajes, R., Gullino, M. L., Van Lenteren, J. C., and Elad, Y. 1999. Integrated pest and diseases management in greenhouse crops. Kluwer Academic Publishers, Dordrecht, The Netherlands.
3. Albritton, D. L., and Watson, R. T. 1992. Methyl bromide and the ozone layer: A summary of current understanding. Pages 3-18 in: Methyl bromide: Its atmospheric science, technology and economics. R. T. Watson, D. L. Albritton, S. O. Andersen, and S. Lee-Bapty, eds. United Nations Environment Programme.
4. Assaraf, M. P., Ginzburg, C., and Katan, J. 2002. Weakening and delayed mortality of *Fusarium oxysporum* by heat treatment: Flow cytometry and growth studies. *Phytopathology* 92:956-963.
5. Bell, C. H., Price, N., and Chakrabarti, B., eds. 1996. The Methyl Bromide Issue. John Wiley & Sons, New York.
6. Camponogara, A., Minuto, A., Gasparrini, G., and Gullino, M. L. 2003. Indagine sui consumi di bromuro di metile per la disinfezione del terreno. *Inform. Fitopatol.* - La difesa delle piante 53(5):24-27.
7. Cao, A., Guo, M., Cao, Z., Zheng, C., Gullino, M. L., Camponogara, A., and Minuto, A. 2002. Sustainable practices for soil disinfection: A project between Italy and China. *Proc. II Int. Conf. Sustainable Agric. food, energy and industry*, Beijing, 2:1492-1500.
8. Cebolla, V., Tuset, J. J., Guinet, N., Molina, A., Mira, J. L., and Hinarejos, C. 1996. New technologies for methyl bromide emission reduction from soil fumigation in Spain. Pages 35-36 in: *Proc. Annu. Int. Res. Conf. MB Alternatives Emission Reduction*, Orlando, FL.
9. Coosemans, J., and Van Assche, C. 1983. Relation of the bromide content in food due to soil disinfection with methyl bromide. *Acta Hort.* 152:315-320.
10. Csinos, A. S., Summer, D. R., Johnson, W. C., Johnson, A. W., McPherson, R. M., and Dowler, C. C. 2000. Methyl bromide alternatives in tobacco, tomato and pepper transplant production. *Crop Prot.* 19:39-49.
11. Cuartero, J., Laterrot, H., and van Lenteren, J. C. 1999. Host-plant resistance to pathogens and arthropod pests. Pages 124-138 in: *Integrated pest and diseases management in greenhouse crops*. R. Albajes, M. L. Gullino, J. C. Van Lenteren, J. C. and Y. Elad, eds. Kluwer Academic Publishers, Dordrecht, The Netherlands.
12. D'Addabbo, T., Sasaneli, N., Lamberti, F., and Carella, A. 2000. Control of root-knot nematodes by olive and grape pomace soil amendments. *Acta Hort.* 532:53-58.
13. Di Primo, P., and Cartia, G. 1998. La biofumigazione del terreno per il contenimento di

- Sclerotium cepivorum* e *Sclerotium rolfsii*. Atti Giornate Fitopatol. 2:677-680.
14. Gamliel, A., Grinstein, A., Beniches, M., Katan, J., Fritsh, J., and Ducom, P. 1998. Permeability of plastic films to methyl bromide: A comparative laboratory study. Pestic. Sci. 53:141-148.
 15. Gamliel, A., Grinstein, A., and Katan, J. 1997. Improved technologies to reduce emissions of methyl bromide from fumigated soil. *Phytoparasitica* 25(Suppl.):21S-30S.
 16. Gamliel, A., Grinstein, A., Peretz, Y., Klein, L., Nachmias, A., Tsror, L., Livescu, L., and Katan, J. 1997. Reduced dosage of methyl bromide for controlling *Verticillium* wilt of potato in experimental and commercial plots. Plant Dis. 81:469-474.
 17. Gamliel, A., and Stapleton, J. J. 1997. Improvement of soil solarization with volatile compounds generated from organic amendments. *Phytoparasitica* 25(Suppl.):31S-38S.
 18. Garibaldi, A., and Gullino, M. L. 1991. Soil solarization in southern European countries, with emphasis on soilborne disease control of protected crops. Pages 227-235 in: Soil Solarization. J. Katan and J. E. De Vay, eds. CRC Press, Boca Raton, FL.
 19. Garibaldi, A., and Gullino, M. L. 1995. Focus on critical issues in soil and substrate disinfection towards the year 2000. Acta Hortic. 382:21-36.
 20. Garibaldi, A., Minuto, A., and Salvi, D. Disinfection of nutrient solution in closed soilless systems in Italy. Acta Hortic. In press.
 21. Gullino, M. L. 1998. Combination of solar heating with chemicals and/or biocontrol agents for soil disinfection. Pages 357-364 in: Proc. Int. Congr. Plastics Agric. Laser Pages Publ. Ltd., Jerusalem.
 22. Gullino, M. L. 2001. Available alternatives for Italy. Pages 47-60 in: Global report of validated alternatives to the use of methyl bromide for soil fumigation. R. Labrada, R. and L. Fornasari, FAO, n. 166.
 23. Gullino, M. L., and Clini, C. 1998. Methyl bromide: The Italian position. Pages 335-340 in: Proc. Alternatives Methyl Bromide Southern European Countries, Arona, Tenerife, Spain.
 24. Gullino, M. L., and Clini, C. 1999. Alternatives to methyl bromide for soil disinfection: Results, problems and perspectives. The Italian view. Pages 54-56 in: Proc. Earth Technologies Forum, Washington, DC.
 25. Gullino, M. L., and Garibaldi, A. 1994. Influence of soilless cultivation on soilborne diseases. Acta Hortic. 361:341-353.
 26. Gullino, M. L., and Kuijpers, L. A. M. 1994. Social and political implications of managing plant diseases with restricted fungicides in Europe. Annu. Rev. Phytopathol. 32:559-579.
 27. Gullino, M. L., Minuto, A., Gilardi, G., Garibaldi, A., Ajwa, H., and Duafala, T. 2002. Efficacy of preplant soil fumigation with chloropicrin for tomato production in Italy. Crop Prot. 21:741-749.
 28. Gullino, M. L., Minuto, A., Minuto, G., and Garibaldi, A. 1998. Chemical and physical alternatives to methyl bromide and their combination in the control of *Rhizoctonia solani* and *Sclerotinia sclerotiorum* in the open field. Pages 693-700 in: Proc. Brighton Crop Prot. Conf.
 29. Gullino, M. L., Minuto, G., Mocioni, M., and Garibaldi, A. 1996. Reduction of dosages of methyl bromide for soil disinfection in Italy. Med. Fac. Landbouww Univ. Gent 61/2b:547-553.
 30. Hoitink, H. A. J., Inbar, Y., and Boehm, M. J. 1991. Status of compost-amended potting mixes naturally suppressive to soilborne diseases of floricultural crops. Plant Dis. 75:869-873.
 31. Katan, J. 1999. The methyl bromide issue: Problems and potential solutions. J. Plant Pathol. 81:153-159.
 32. Katan, J. 2000. Soil and substrate disinfection as influenced by new technologies and constraints. Acta Hortic. 532:29-35.
 33. Katan, J., and De Vay, J. E. 1991. Soil solarization. CRC Press, Boca Raton, FL.
 34. Lamberti, F. 2001. Il punto sui nematodi dopo la messa al bando del bromuro di metile. Inform. Fitopatol. - La Difesa delle piante. 51:31-34.
 35. Laterot, H. 1991. Lutte génétiques contre les parasites des cultures maraichères sous abris. Phytoma 428:41-45.
 36. Lazarovits, G., Tenuta, M., and Conn, K. L. 2000. Utilization of high nitrogen and swine manure amendments for control of soilborne diseases: Efficacy and mode of action. Acta Hortic. 532:59-64.
 37. Lazzeri, L., and Manici, L. 2000. The glucosinolate-myrosinase system: A natural and practical tool for biofumigation. Acta Hortic. 532:89-96.
 38. Lee, J. M. 1994. Cultivation of grafted vegetables. Current status, grafting methods and benefits. HortScience 29:235-239.
 39. Lodha, S., Sharma, S. K., and Aggarwal, R. K. 1997. Solarization and natural heating of irrigated soil amended with cruciferous residues for improved control of *Macrophomina phaseolina*. Plant Pathol. 46:186-190.
 40. Lower House. 1981. Report of the Netherlands Parliamentary session 1980-1981, 16 400, Chapter XIV, 50, 1-23.
 41. Minuto, A., Gilardi, G., Gullino, M. L., and Garibaldi, A. 1999. Reduced dosages of methyl bromide applied under gas-impermeable plastic films for controlling soilborne pathogens of vegetable crops. Crop Prot. 18:365-371.
 42. Minuto, A., Gilardi, G., Pomè, A., Garibaldi, A., and Gullino, M. L. 2000. Chemical and physical alternatives to methyl bromide for soil disinfection: Results against soilborne diseases of protected vegetable crops. J. Plant Pathol. 82:179-186.
 43. Minuto, A., Minuto, G., Gullino, M. L., and Garibaldi, A. 1998. Prove sulla riduzione delle dosi di impiego di bromuro di metile per la disinfezione del terreno. Atti Giornate Fitopatol. 2:671-676.
 44. Minuto, A., Pomè, A., Gullino, M. L., and Garibaldi, A. 2000. Lotta al marciume basale su gerbera con l'uso di fumiganti. Colture Protette 29(2):109-112.
 45. Minuto, G., Minuto, A., Garibaldi, A., and Gullino, M. L. 1995. Disinfezione del terreno con l'impiego combinato di dazomet e della solarizzazione. Colture Protette 24(11):95-101.
 46. Molina, M. J., and Rowlands, F. S. 1974. Stratospheric sink for chlorofluoromethanes: Chlorine atom catalyzed destruction of ozone. Nature 249:810-814.
 47. Munneke, D. E., Kolbezen, M. J., and Bricker, J. L. 1982. Effects of moisture, chloropicrin, and methyl bromide singly and in mixtures on sclerotia of *Sclerotium rolfsii* and *Verticillium albo-atrum*. Phytopathology 72:1235-1238.
 48. O Anderson, S., and Sarma, K. M., eds. 2002. Protecting the ozone layer. The United Nations history. United Nations Environmental Programme.
 49. Ohr, H. D., Sims, J. J., and Grech, N. M. 1996. Methyl iodide, an ozone safe alternative for methyl bromide as soil fumigant. Plant Dis. 80:731-735.
 50. Penkett, S. A., Jones, B. M. R., Rycroft, M. J., and Simmons, D. A. 1985. An inter-hemispheric comparison of the concentrations of bromine compounds in the atmosphere. Nature 318:550-553.
 51. Ristaino, J. B., and Thomas, W. 1997. Agriculture, methyl bromide, and the ozone hole. Can we fill the gaps? Plant Dis. 81:964-977.
 52. Robock, A. 1996. Stratospheric control of climate. Science 272:972-973.
 53. Rodrigues-Kabana, R. 1998. Alternatives to methyl bromide for soil disinfection. Pages 17-31 in: Proc. Alternatives Methyl Bromide Southern European Countries, Arona, Tenerife, Spain.
 54. Rowlands, I. 1998. EU policy for ozone layer protection. Global Competition and EU Environmental Policy. J. Golub, ed. Routledge, London.
 55. Runia, W. T. 2000. Steaming methods for soils and substrates. Acta Hortic. 532:115-123.
 56. Stanghellini, M. E., and Rasmussen, S. L. 1994. Hydroponics. A solution for zoospore plant pathogens. Plant Dis. 78:1129-1138.
 57. Taylor, R. 2001. Facing the future without methyl bromide - Are alternatives available to this versatile fumigant? Phytoparasitica 29:3-5.
 58. Tenuta, M., and Lazarovits, G. 2002. Ammonia and nitrous acid from nitrogenous amendments kill the microsclerotia of *Verticillium dahliae*. Phytopathology 92:255-264.
 59. Tognoni, F., and Serra, G. 1994. New technologies for protected cultivations to face environmental constraints and to meet consumer's requirements. Acta Hortic. 361:31-38.
 60. United Nations Environmental Programme. 1998. Report of Technical and Economic Assessment Panel of the Montreal Protocol to the X Meeting of the Parties, Cairo, Egypt.
 61. United Nations Environmental Programme. 2002. Scientific Assessment Panel of the Montreal Protocol on Substances that Deplete the Ozone Layer. Scientific Assessment of Ozone Depletion. 2002. Executive Summary, 21 pages.
 62. United Nations Environmental Programme. 2002. Production and Consumption of Ozone Depleting Substances under the Montreal Protocol 1986 - 2000. UNEP.
 63. Vanachter, A., Feyaerts, J., Van Wambeke, E., and Van Assche, C. 1981. Bromide concentrations in water after methyl bromide soil disinfection. II. Relation between leaching of methyl bromide fumigated greenhouse soils and bromide concentrations in the surrounding surface water. Med. Fac. Landbouww. Rijksuniv. Gent. 40/1:351-358.
 64. Van Haasteren, J. 2002. The methyl bromide phase out in soil fumigation in The Netherlands, 1979-1992. Pages 257-258 in: Protecting the ozone layer. The United Nations history. S. O. Anderson and K. M. Sarma, eds. United Nations Environmental Programme.
 65. Vannacci, G., and Gullino, M. L. 2000. Use of biocontrol agents against soil-borne pathogens: Results and limitations. Acta Hortic. 532:79-87.
 66. Wohanka, W. 1995. Disinfection of recirculating nutrient solutions by slow sand filtration. Acta Hortic. 382:246-255.
 67. Wolfsy, S. C., Mc Elroy, M. B., and Yung, Y. L. 1976. Chemistry of atmospheric bromine. Chem. Abstr. 84, n. 110882.
 68. World Meteorological Organization. 1994. Scientific Assessment of Ozone Depletion 1994. Global Research and Monitoring Project N. 37, Geneva.
 69. Young, D. C. 1990. GY-81, a new concept in soil fumigation. Pages 79-85 in: Proc. Brighton Crop Prot. Conf.
 70. Yung, Y. L., Pinto, J. P., Watson, R. T., and Sander, S. P. 1980. Atmospheric bromine and ozone perturbations in the lower stratosphere. J. Atmos. Sci. 37:339-353.

Maria Lodovica Gullino

Andrea Camponogara

Giuliana Gasparrini

Valeria Rizzo

Corrado Clini

Angelo Garibaldi

Dr. Gullino is professor of biological and integrated plant disease management, School of Biotechnology, with primary interest in plant disease management, biological control of diseases, and sustainable plant protection. She has coauthored five books and published over 300 scientific articles and reviews in Italian and international journals on biological and integrated disease management, fungicide resistance, and risks related to the release of biocontrol agents. She is chair of the Italian Society for Crop Protection (A.I.P.P.) and the Italian Association of the Agricultural Scientific Societies (AISSA), and vice-president of the International Society for Plant Pathology (ISPP). Dr. Gullino is a member of international committees dealing with environmental aspects of the use of pesticides, consultant to the Italian Ministry for the Environment and Territory on agro-environmental issues, chair of the Committee on International Affairs of the University of Torino, and member of the Committee on Research Planning of the University of Torino. She is editor of *Informatore Fitopatologico - La Difesa delle piante*, a journal belonging to the group *Il Sole-24 Ore*, and director of the Center of Competence for the Innovation in the Agro-environmental Sector (AGRINNOVA) of the University of Torino.

Dr. Camponogara received his M.S. degree in agricultural science from the Faculty of Agriculture of the University of Torino (Italy) in 1998 and his Ph.D. in biological and integrated pest management from the University of Torino in 2002. His primary interest is the scientific, technical, and economic aspects related to the transfer of methyl bromide alternative technologies to developing countries. Since 1998, he has been detached by the University of Torino to the Italian Ministry for the Environment and Territory with the following duties: preparation, coordination, and implementation of cooperative projects in the agro-environmental sector in the framework of bilateral and multilateral cooperation programs; and technical, economic, and regulatory measures for the implementation of the Montreal Protocol and EU Regulation 2037/2000 on ozone-depleting substances.

Ms. Gasparrini is director of the Regional Conventions and Protocols, EU Directives and Regulations Division, Directorate for Global Environment, International and Regional Conventions of the Italian Ministry for the Environment and Territory. She represents the Italian government at all high-level meetings at EU and UN-EC levels, as well as several regional conventions concerning access to information, public participation in decision making, and access to justice in environmental matters; long-range transboundary air pollution; environmental impact assessment; protection and use of transboundary watercourses and international lakes; and industrial accidents.

Ms. Rizzo is director of the International Affairs and Bilateral Cooperation Division, Directorate for Global Environment, International and Regional Conventions of the Italian Ministry for the Environment and Territory. She represents the Italian government to the United Nations Conventions and Protocols on the global environment (United Nations Framework Convention on Climate Change, the Montreal Protocol on substances that deplete the ozone layer, the international negotiations on sustainable development, atmospheric pollution, G8 environment, desertification). She is a member of working groups and interministerial commissions and is responsible for procurement activities. She is experienced in bidding and procurement procedures in the framework of bilateral and international cooperation programs.

Dr. Clini is director general of the Italian Ministry for the Environment and Territory, responsible for the international environmental treaties (climate change, ozone layer protection, sustainable development), international cooperation for the protection of the global environment, and European environmental regulations. He is co-chair of the European Environmental and Health Committee of the United Nations Economic Commission for Europe, vice chair of the European Environmental Protection Agency, and professor of ecology at the University of Parma. As director general of the Ministry of the Environment and Territory, during the 1990s he was responsible for the implementation of regulations on air and noise pollution, industrial safety, and environmental standards for the industrial and transportation sectors. In 2000/2001, he was co-chair of the G8 task force on renewable energies. He was head of the Italian delegation to the Rio Conference on Environment and Development in 1992 and to the Kyoto Conference on Climate Change in 1997.

Dr. Garibaldi is vice-chancellor of the University of Turin, professor of plant disease management, and member of numerous Italian and international scientific associations. He has published five books and many articles in Italian and international journals on biological control, resistance to fungicides, and diseases of ornamental crops. He is consultant to the Ministry for Health for the registration of new biological products to be used in crop protection. Dr. Garibaldi was dean of the Faculty of Agriculture from 1990 to 1996, president of the Council of Degree Course in Agricultural Sciences from 1984 to 1990, and president of the Italian Phytopathological Association (AFI) from 1982 to 1988. He has taught at the American University of Beirut (Lebanon) and at the Somali National University of Mogadishu. He has been awarded the Van der Brande prize from the University of Gent (Belgium) and the gold medal for service to Science and Culture of the Italian Ministry of University and Research.