Reduced Dosage of Methyl Bromide for Controlling Verticillium Wilt of Potato in Experimental and Commercial Plots

A. Gamliel and A. Grinstein, Laboratory for Pest Management Application, ARO The Volcani Center, Bet Dagan 50250 Israel; Y. Peretz, Hevel Maon, Mobile post Hanegev 85465, Israel; L. Klein, Bromine Compounds Ltd., Agricultural Department, P.O.B. 180 Beer Sheva, Israel; A. Nachmias, L. Tsrer, and L. Livescu, ARO, Gilat Experiment Station; and J. Katan, Department of Plant Pathology and Microbiology, The Hebrew University of Jerusalem, Faculty of Agriculture, Rehovot, 76100 Israel

ABSTRACT

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The use of gas-impermeable films to reduce the dosage of methyl bromide (MB) required to control Verticillium wilt in potatoes was examined in field experiments, conducted in soils naturally infested with *Verticillium dahliae*. The incidence and severity of Verticillium wilt were significantly reduced (by 74 to 94%) by fumigation with MB at 50 g/m² under standard low density polyethylene (LDPE) or at 25 g/m² under gas-impermeable films. Fumigation at 25 g/m² under LDPE was less effective. Disease severity was inversely correlated ($r^2 = 0.89$ to 0.91) with chlorophyll content in the leaves. Fumigation also reduced (by 89 to 100%) stem colonization by the pathogen. Potato yield in the fumigated plots was significantly higher (26 to 69%), than in their nonfumigated counterparts, and was inversely correlated with disease index ($r^2 = 0.69$ to 0.9). The percentage of high-value tubers (above 45 g) was 52 to 56% of total yield in the fumigated plots as compared with 32 to 40% in the nonfumigated controls. Thus, fumigation also improved the commercial quality of tuber yield. Effective control of *V. dahliae* and yield increases following MB fumigation at the recommended dosage or at a reduced dosage with gas-impermeable films was also observed in a consecutive crop. These results were verified in a large-scale field experiment using commercial applications, further demonstrating the feasibility of reducing MB dosages under farm conditions, without reducing its effectiveness in terms of disease control and yield improvement.

Additional keywords: soil disinfection

Verticillium wilt (early dying) of potato caused by *Verticillium dahliae* is a common disease in Israel (3,10,13,16). In severe cases, diseased plants collapse and die before the end of the season, resulting in a considerable decrease in tuber size and yield. In some regions, two successive potato crops are grown. In others, peanuts (which are also highly susceptible to *V. dahliae*) and potatoes are grown in rotation. Such agricultural practices are conducive to the buildup of pathogen inoculum in soil.

Verticillium wilt of potato can be controlled by soil disinfection using methyl bromide (MB), metham sodium, or soil solarization (3,6,8,10,13,16-18). Soil fumigation with MB at 50 g/m² is a common practice for the control of a wide spectrum

of soilborne pathogens, including Verticillium wilt in many crops (1,13,15-18). However, concern regarding this fumigant's possible role in ozone depletion (1) and the regulations to reduce its consumption or phase it out altogether raise a need for development of methods to reduce MB emission and dosage. The commonly used films for MB fumigation, e.g. low density polyethylene (LDPE 30µm thickness), provide poor barrier (4,7,22), allowing MB's escape to the atmosphere during the fumigation process. Studies carried out in the Netherlands (7) and other countries (1) have shown that gas-impermeable films minimize this escape, thereby maintaining a relatively higher MB concentration for a certain period in the soil. This enables dosage reduction without reducing effectiveness of pest control, based on the assumption that extending a pathogen's exposure to a fumigant enables dosage reduction (9,14,15). The objective of this study was to evaluate the effectiveness of gas-impermeable films with reduced dosages of MB in controlling Verticillium wilt in potato and in improving yield and quality for one or two successive seasons in experimental and commercial plots.

MATERIALS AND METHODS

Selection of gas-impermeable films in small field plots. Various films were tested for their permeability to MB in the laboratory as previously described (22). Films having a permeability rate of less than 1 g/m² h (as compared with LDPE, which has a permeability rate of over 50 g/m² h) at temperature of 50°C, were considered gas-impermeable and were further tested in the field. Concentrations of MB under plastic films were determined at the experimental farm of the Hebrew University, Rehovot, in sandy soil. Plots (4 × 4 m) were outlined and trenches (30 cm deep) were cut to bury the plastic edges. Nylon 11 sampling tubing (5 mm diameter, 5 m long) were placed in the center of each plot at various depths before plastic tarp was laid. The buried end of the tubing was protected with a porous plastic cylinder (10 cm long × 15 mm diameter). The other end was extended to the area outside the tarped plot. Four plastic films were tested in triplicate: LDPE (Polyon, Kibbutz Barkai, Israel), a standard film for fumigation, with MB at 50 and 25 g/m², and three gas-impermeable films – Bromotech film (Smith Bros., UK), Barromid (Plastopil, Kibbutz Hazorea, Israel) and Hytibarr (Hyplast, Belgium), with MB at 25 g/m². All films were 30 µm thick. Each tested film was laid on three plot replicates in a randomized block design. MB (Methabrom, 98% active ingredient, Bromine Compounds Ltd., Beer Sheva, Israel), was applied through drip lines placed under the film, using the hot gas method (12). MB concentration in the soil was determined periodically following its application over a 5-day period by connecting the sampling tubing to a GowMac 20-800 gas analyzer (GowMac Instrument Co. Bridgewater, NJ). The concentration × time ($C \times T$) product (9) for each film was calculated as the area under the concentration curve.

Experimental design and soil treatments. Three field experiments were conducted in southern Israel from 1993 to 1995 in loessial (sierozon) soil. Experiment 1 was initiated in the fall of 1993 at Kibbutz Re'im, in a field with a long history of potato cropping and naturally infested with *V. dahliae*. Experiment 2 was conducted in the spring of 1994 at the ARO Gilat experiment station, Gilat, in a plot with a

Corresponding author: A. Gamliel
Fax: 972 3 9604704
E-mail: vpestic@volcani.agri.gov.il

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long history of potato cropping and heavily infested with *V. dahliae*. The commercial field experiment (experiment 3) was also at Kibbutz Re'im in the fall of 1994. After fumigation, potato-seed tubers were planted at a depth of 15 cm by commercial planter, two rows per bed.

In experiments 1 and 2, each plot was four beds wide (bed width 1.93 m), 15 m long. The two central beds were used for data collection. Fumigation treatments were arranged in a randomized complete block design with four replications per treatment. Fumigation was conducted at the end of August 1993. In experiment 1 the plastic films used were LDPE (Polyon, Kibbutz Barkai, Israel), with MB at 50 and 25 g/m², and Bromotech and Barromid with MB at 25 g/m². In experiment 2, the plastic films used were LDPE (Polyon, Kibbutz Barkai, Israel), with MB at 50 and 25 g/m², and Bromotech and Hytibarr at 25 g/m². The plastic sheets were laid down manually and the edges buried manually in trenches to a depth of 20 cm. MB was applied by the hot gas method (12) through perforated lay-flat polyethylene tubes that

had been placed on each bed before tarping, as described in the small plot tests. Nylon net bags containing naturally produced microsclerotia of *V. dahliae* obtained from infected potato stems were buried at depths of 20 and 40 cm in each plot before tarping to evaluate the efficacy of the fumigation treatments. Viability of microsclerotia was evaluated after their removal from the soil by placing them individually on a selective medium and incubating at 18°C for 21 days (2). Percent mortality was calculated by comparing with untreated controls.

Experiment 3 was carried out on a commercial scale in large plots to assess the effectiveness of gas-impermeable films under farmer conditions. Each treatment consisted of a single plot with six adjacent beds (total 12 m wide × 400 m in length = 0.4 ha). MB and plastic tarp were mechanically applied in August 1994 with a commercial fumigation machine (Technohak, Israel) equipped with hollow shanks (30 cm apart) injecting the chemical to a depth of 30 cm, and with a tarp layer covering the treated soil immediately after the

injection in a single operation. Two plastic films were used: LDPE (Ram Plastics, Israel) with MB at rates of 50 and 25 g per m², and Barromid with MB at 25 and 15 g/m².

The plastic films were kept on the fumigated plots for 5 days, at which time they were manually removed.

Cultural practices. Potato (*Solanum tuberosum* L. cv. Nicola, Hevel Maon seeds, Israel, or imported from Holland) was grown in all plots as the first crop after fumigation. The potato crops in experiments 1 and 3 were planted in October 1993 and 1994, respectively. The potato crop in experiment 2 (Gilat) was planted in February 1994. Field preparation at each site consisted of cultivation practices common to commercial potato production in this region, including pre-irrigation, broadcast application of composted cow manure, and bed shaping (193 cm between centers) before fumigation. All fields were sprinkle-irrigated and farmed according to the recommendation for commercial potato production in this region. The field in experiment 1 was left fallow for 7 months after the end of the first crop and a second potato crop was planted in October 1994. Eggplants (*Solanum melongena* L. cv. Black Beauty, Hazera, Israel) were planted in experiment 2 in September 1995, following removal of the potato crop.

Assessment of chlorophyll, stem colonization, disease severity, and yield. Chlorophyll content of potato leaves was determined during crop growth in experiments 1 and 2. Ten leaves (the fourth leaf from the top) were collected from each plot, washed, and blotted on filter paper. Chlorophyll content was measured with a SPAD-502 chlorophyll meter (Minolta, Ramsey, NJ) (19). Measurements were taken from each leaflet (5 to 8 readings per leaf). Results are expressed in the instrument's units on a scale of 0 to 50.

In experiments 1 and 2, potato stems were periodically sampled from each plot at time intervals during crop growth. In experiment 3, four samples were taken from each treatment along the rows. The stems were rated for *Verticillium* severity

Fig. 1. Effect of film type and MB dosage on gas concentration (C) in soil and on $C \times T$ values. LDPE — low density polyethylene; Bromotech, Barromid, and Hytibarr are gas-impermeable films. Different letters in $C \times T$ column denote significant differences among films ($P \leq 0.05$).

Table 1. Effect of film type and methyl bromide (MB) dosage on *Verticillium* wilt in potatoes, experiment 1 (Re'im site)^a

Film type ^v	MB dosage (g/m ²)	Year 1				Year 2			
		15 Dec 93		21 Jan 94		21 Jan 95			
		Disease incidence ^w (%)	Disease index ^x	Chlorophyll units ^y	Disease incidence (%)	Disease index	Chlorophyll units	Disease incidence (%)	Disease index
None	None	77 a ^z	1.0 a	29.0 b	85 a	1.77 a	26.0 b	92 a	2.55 a
LDPE	50	10 c	0.1 c	37.9 a	16 c	0.23 c	32.5 a	42 b	0.71 c
LDPE	25	26 b	0.4 b	35.2 a	41 b	0.64 b	32.5 a	87 a	1.47 b
Bromotech	25	20 b	0.1 c	37.3 a	25 c	0.33 c	33.5 a	46 b	0.46 c
Barromid	25	5 c	0.2 c	36.8 a	12 c	0.14 c	31.3 a	48 b	0.58 c

^a Experiment was conducted with two successive potato crops. First crop was planted on 11 October 1993, the second on 19 October 1994.

^v LDPE — low density polyethylene; Bromotech and Barromid — gas-tight films.

^w Percentage of plants showing disease symptoms.

^x Disease index on 0 to 3 scale, where 0 = no symptoms and 3 = wilted stem and presence of microsclerotia on the stems.

^y Chlorophyll content was determined with chlorophyll meter SPAD-502. Results are expressed as the instrument units.

^z Different letters within each column denote significant differences among treatments ($P \leq 0.05$).

on an index scale of 0 to 3, where 0 = no symptoms and 3 = wilted plants with micro-sclerotia on the stem.

Stem colonization by *V. dahliae* was assayed in experiment 2 as described previously (20). Stem segments 1 cm long were taken from six plants per plot. Segments were pooled, surface disinfected in 1% NaClO for 5 min, and rinsed in sterile water. The segments were then suspended in 10 ml sterile water and pulverized (Ultra-Turrax blender at 500 rpm) for 1 min at 5°C. The homogenized suspension was further diluted and 0.2-ml samples from the appropriate dilution were spread on dishes containing selective sorbose (0.2%) medium supplemented with 100 mg/l streptomycin sulfate. Plates were incubated for 10 days in the dark at 27°C.

Plots were harvested after 120 days of growth in all experiments. Potato tubers were manually harvested from a 6-m bed (1.93 m width, total area 11.6 m²), from the center of each plot in experiments 1 and 2. In experiment 3, each plot was harvested mechanically using standard commercial machines and weighed at Hevel Maon's packing facilities. Tubers were counted and graded according to standard marketable size.

Statistical analyses. Disease incidence, chlorophyll content, and tuber yield were analyzed by analysis of variance followed by mean separation using Fisher's protected least significant difference test. Data taken as percentages were arcsine-transformed before analysis. Nonparametric variables such as disease index were analyzed using the rank procedure followed by analysis of variance. Analyses also included correlation and regression. All analyses were performed with the SAS program (SAS Institute Inc., Cary, NC, release 6.04 for personal computer) at $P \leq 0.05$.

RESULTS

Permeability of films to MB in small-plot tests. Plots covered with each of the three gas-impermeable films tested retained higher concentrations of MB in the

soil, for longer periods, as compared with those covered by standard LDPE, at the two tested rates (Fig. 1). Concentrations of the gas applied at 50 g/m² under LDPE decreased to undetectable levels after less than 48 h. In contrast, MB was detected at measurable levels for at least 80 hours after its application when the reduced rate (25 g/m²) under gas-impermeable films was used (Fig. 1). $C \times T$ values of MB at the reduced rate of 25 g/m² under the Barro-mide impermeable film were significantly higher than those achieved under LDPE with an initial dosage of 50 g/m² (Fig. 1).

Effect of film type and MB dosage on the pathogen and Verticillium wilt. In both experiments 1 and 2, micro-sclerotia of *V. dahliae* were effectively controlled (100% mortality) at soil depths of 20 and 40 cm by all MB treatments, both at 50 and 25 g/m². First symptoms of foliar chlorosis

in the untreated plots appeared in these two experiments 70 days after planting, later followed by wilt and early dying. Foliar chlorosis in the untreated plots was reflected by a significant 10 to 24% reduction in chlorophyll content (Tables 1 and 2). Verticillium wilt was effectively controlled by MB fumigation at either 50 g/m² under LDPE or 25 g/m² under gas-impermeable film. Fumigation at 25 g/m² under LDPE was less effective (Tables 1 and 2). Disease incidence in the untreated plots ranged from 77 to 85%, as compared with 5 to 25% in plots fumigated with MB at a rate of 50 g/m² under LDPE or 25 g/m² under gas-impermeable films. Disease incidence under LDPE at 25 g/m² ranged from 26 to 64%. The same trend was obtained using the disease severity parameter. A significant ($P \leq 0.05$) and high correlation ($r^2 = 0.94$) was obtained between dis-

Fig. 2. Relationship between disease index of Verticillium wilt (scale 0 to 3, where 0 = no disease symptoms and 3 = dead plant with micro-sclerotia on the stem) and chlorophyll content (expressed in instrument units) in experiment 1, first year. Significance of regression line, $P = 0.012$.

Table 2. Effect of film type and methyl bromide (MB) dosage on Verticillium wilt in potatoes, experiment 2 (Gilat site)^a

		Potato (first crop)						Eggplant (2nd crop)
		20 Apr 94			25 May 94			
Film type ^v	MB dosage (g/m ²)	Chlorophyll content ^w (units)	Disease incidence ^x (%)	Disease index ^y	Disease incidence (%)	Disease index	Stem colonization (CFU/cm)	
None	None	34.4 b ^z	80 a	2.25 a	83 a	2.40 a	722 a	48.0 a
LDPE	50	40.2 a	12 c	0.36 c	14 c	0.40 c	2.1 c	0 b
LDPE	25	38.3 a	52 b	0.65 b	64 b	1.10 b	83 b	0.5 b
Bromotech	25	39.1 a	10 c	0.15 c	14 c	0.42 c	0 c	0.5 b
Hytibarr	25	39.5 a	15 c	0.15 c	20 c	0.35 c	0 c	3.3 b

^a Potato crop was planted in 10 February 1994 and harvested in June 1995. Eggplants were planted in October 1994.

^y LDPE — low density polyethylene, Bromotech and Hytibarr film — gas-tight films.

^w Chlorophyll content was determined with chlorophyll meter SPAD-502. Results are expressed as the instrument units.

^x Percentage of plants showing disease symptoms.

^y Disease index on a 0 to 3 scale, where 0 = no symptoms and 3 = wilted stem and presence of micro-sclerotia on the stems.

^z Different letters within each column denote significant differences among treatments ($P \leq 0.05$).

ease incidence and disease index in experiments 1 and 2. Chlorophyll content was highly and inversely correlated with disease index after 65 days in experiment 1 (Fig. 2). A similar trend ($Y = 33.95 - 1.09x - 1.04x^2$; $r^2 = 0.914$) was also obtained in experiment 2. Changes in disease incidence and severity were also reflected in lower colonization of potato stems by *V. dahliae* in the fumigated plots as compared with the untreated plots (89 to 100% reduction; Table 2). Plants in untreated plots in experiments 1 and 2 collapsed 4 weeks before harvest. In contrast, plants grown in the fumigated plots did not collapse until harvest.

Effect of film type and MB dosage on potato yield. In experiment 1, yield of potato tubers was significantly higher in the fumigated vs. untreated plots (26 to 40% increase; Table 3). In experiment 2, only MB at a rate of 50 g/m² under LDPE or at a rate of 25 g/m² under gas-impermeable films significantly increased (65 to 69%) tuber yield (Table 4). Yield in the plots treated with MB at 25 g/m² under LDPE did not differ significantly from that in the untreated plots. Fumigation in experiment 2 increased the number of tubers by 23 to 30%. The percentage of large (high value > 45 mm diameter) tubers was 52 to 56% in the fumigated plots as compared with 32 to 40% in the unfumigated control (Tables 3 and 4). Thus, fumigation of *Verticillium*-infested plots also improved the marketable value of the crop. Yield was inversely correlated with severity of *Verticillium* disease in experiment 2 (Fig. 3). A similar and significant trend was also obtained in experiment 1 ($Y = 3.64 - 0.505x$; $r^2 = 0.689$).

Effect of film type and MB dosage on Verticillium wilt and potato yield in a commercial field experiment. The incidence and severity of *Verticillium* wilt were significantly reduced by fumigation with MB at either 50 g/m² under LDPE or 25 g/m² under a Barromid gas-impermeable film in experiment 3 (76 to 100% reduction), whereas fumigation at 25 g/m² under LDPE was less effective (Table 5). Effective control of *Verticillium* was even observed at 15 g/m² under the gas-impermeable film. Yield of potato tubers in all

fumigation treatments was significantly higher than that in the unfumigated plots. Such an increase in yield by fumigation was also recorded when the whole plot of each treatment was harvested in a fully commercial manner using a potato harvester and weighed in the packing-house (Table 5), thus further validating the re-

sults from the experimental plots (Tables 1 to 4).

Long-term effect. An extended effect of fumigation treatments was observed in experiment 1, in a second consecutive potato crop (Table 1). Disease incidence and severity increased in all treatments relative to the first crop, especially in the

Table 4. Effect of film type and methyl bromide (MB) dosage on potato yield, experiment 2 (Gilat site)^x

Film type ^y	MB dosage (g/m ²)	Number of tubers / m ²	Ton/ha			Control (%)
			Small tubers (< 45 mm)	Large tubers (> 45 mm)	Total weight	
None	None	34.7 b ^z	10.6 b	7.0 b	17.6 b	100
LDPE	50	45.2 a	14.0 a	15.8 a	29.8 a	169
LDPE	25	42.8 a	11.6 ab	13.5 a	25.1 ab	143
Bromotech	25	43.9 a	12.5 a	17.2 a	29.7 a	169
Hytibarr	25	44.3 a	13.1 a	15.9 a	29.0 a	165

^x Potato crop was planted in February 1994 and harvested in June 1995. Tubers were harvested from a 6-m bed (11.6 m²) and graded for size according to their diameter.

^y LDPE — low density polyethylene; Bromotech and Barromid — gas-tight films.

^z Different letters within each column denote significant differences among treatments ($P \leq 0.05$).

Fig. 3. Relationship between disease index of *Verticillium* wilt (scale 0 to 3, where 0 = no disease symptoms and 3 = dead plant with microsclerotia on the stem) and yield of potato tubers (experiment 2). Significance of regression line, $P = 0.025$.

Table 3. Effect of film type and methyl bromide (MB) dosage on yield of potatoes, experiment 1 (Re'im site)^x

Film type ^y	MB dosage (g/m ²)	Year 1, ton/ha			Control (%)	Year 2, ton/ha			Control (%)
		Small tubers (<45 mm)	Large tubers (> 45 mm)	Total weight		Small tubers (< 45 mm)	Large tubers (> 45 mm)	Total weight	
None	None	19.2 a ^z	9.0 b	28.2 b	100	10.2 b	1.0 b	11.2 b	100
LDPE	50	17.4 a	22.3 a	39.7 a	140	14.5 a	4.1 a	18.6 a	166
LDPE	25	15.7 a	19.9 a	35.6 a	126	12.9 ab	3.4 a	16.3 a	145
Bromotech	25	16.6 a	20.2 a	36.8 a	130	15.2 a	4.6 a	19.8 a	177
Barromid	25	18.2 a	20.1 a	38.3 a	136	16.8 a	4.2 a	21.0 a	187

^x Experiment was conducted during two successive potato crops. First year crop was planted in October 1993 and harvested in February 1994, the second crop was planted in October 1994 and harvested in February 1995. Tubers were harvested from 6 m bed (11.6 m²) and graded for size according to their diameter.

^y LDPE — low density polyethylene; Bromotech and Barromid — gas-tight films.

^z Different letters within each column denote significant differences among treatments ($P \leq 0.05$).

plots fumigated at 25 g/m² under LDPE (increase from 41 to 87%), which did not differ significantly from untreated plots. However, disease control was still evident in the plots fumigated at a rate of 50 g/m² under LDPE or at 25 g/m² under gas-impermeable films; disease reduction ranged from 46 to 52%. Plants in the untreated plots and those fumigated at 25 g/m² under LDPE collapsed after 90 days of growth. The yield in the second year in all treatments was lower than that of the previous year, but was significantly higher in the fumigated plots than in their nonfumigated counterparts (Table 3). Yield was inversely correlated with severity of *Verticillium* disease, ($Y = 2.261 - 0.413x$; $r^2 = 0.868$), similar to the trend observed with the first crop.

In experiment 2, eggplants were planted as the second crop after potatoes. Disease incidence after 4 weeks was 48% in the nontreated plots as compared with 0 to 3.3% in the fumigated plots (Table 2). Forty days after planting, the crop was destroyed by a severe sandstorm and the experiment was terminated.

DISCUSSION

Verticillium wilt of potato was effectively controlled by a reduced dosage of MB under gas-impermeable films. These films retained higher concentrations of MB for longer periods in the soil, as compared with LDPE, through which MB dissipated within 48 h. This resulted in higher $C \times T$ values and improved disease control. Effectiveness of gas-impermeable films was demonstrated with all tested parameters: pathogen control, chlorophyll content, reduction in disease incidence and severity, increase in yield and quality, and in a lasting effect for two consecutive seasons. Results were verified at various sites and years, in two experimental plots and one commercial field experiment, thereby demonstrating the reproducibility of the results. The effective control of *Verticillium* wilt was reflected in a reduction of both disease incidence and severity on potato plants, with a good correlation be-

tween the two parameters. Disease control was accompanied with concomitant reduction in stem tissue colonization (Table 2). Extending the exposure time does not always result in a proportional decrease in fumigant dosage required to obtain the same level of pathogen control (9,14,15). Nevertheless, it does enable a reduction of fumigant dosage. Results from our studies clearly show that the use of gas-impermeable films prolonged the exposure time (Fig. 1) while maintaining effective disease control (Tables 1, 2 and 5), thereby enabling a dosage reduction without a concomitant reduction in disease control effectiveness. In contrast to gas-impermeable films, LDPE at a reduced dosage was less effective than LDPE at the standard dosage in most cases, and was ineffective in controlling *Verticillium* wilt of potatoes in a second consecutive crop. This results from the high permeability of LDPE to MB (Fig. 1) (4,7) and the consequent rapid dissipation of MB from the soil. Therefore, unless a gas-impermeable film is used, the recommended dosage of MB should not be reduced in order to ensure full benefits from this fumigant. This is in accordance with results obtained in Israel with potatoes (16).

Yield of potato tubers increased following MB treatments in most cases relative to the untreated plots. Tuber quality as determined by tuber size also improved. Apparently, this disease affects both tuber formation and yield accumulation (11,16,21). A significant inverse correlation between disease level and yield was obtained, indicating the potentially detrimental effect of *Verticillium* on potato yield. Such harmful effects of *Verticillium* wilt on potato yield and quality has been shown in many experiments, using disinfection as a tool for assessing disease loss (3,8,10,16,17). A 30 to 50% reduction in yield by early dying has been recorded (18). The effect on yield also depends on the cultivar (5). In a five-year study in the Negev region of Israel, MB increased yield by 21 and 83% in two cultivars, which were tolerant and susceptible to *Verticillium* wilt, respectively

(16). Methyl bromide fumigation also effectively reduced *Verticillium* infection of daughter tubers.

A long-term effect of MB at a reduced dosage under gas-impermeable films was observed in experiment 1 with two potato crops as well as in experiment 2 with eggplant as the second crop. An extended effect covering more than one crop enables a reduced number of applications and consequently a cost reduction per crop. This and the reduction in dosage by using gas-impermeable films should reduce the emission of MB to the atmosphere. Sanitation, the use of pathogen-free propagation, and other cultural steps to avoid soil recontamination by pathogens are essential in order to fully exploit the benefits of the long-term effects of MB fumigation. Thus, the long-term effect of MB fumigation has significant economic benefits in addition to reducing application frequency. A carryover of the biocidal effects of soil disinfection into other crops has been previously recorded (6,17).

Effective control of *Verticillium* wilt was also observed under commercial application. Proper transfer of a new technology to the farmer requires an intermediate stage during which the results obtained under experimental conditions are put to the test at a commercial scale. This procedure permits the identification of problems that may arise during commercial application, but are not elucidated when the technology is applied very carefully in experimental plots of relatively small size. An upscaling scheme enables an evaluation of the feasibility of a commercial application of a new technology. The results obtained here under commercial conditions (Table 5) concurred with those obtained in the field experiments (Tables 1 to 4) indicating this technology's potential for use by farmers and contractors under realistic farming conditions.

Methyl bromide is an important agent for controlling *Verticillium* wilt and other soilborne pathogens in various crops under many agricultural regimes (1,15,17). The use of gas-impermeable films and other

Table 5. Effect of film type and methyl bromide (MB) dosage on *Verticillium* wilt in potatoes. Commercial experiment (Re'im site)^s

Film type ^t	MB dosage (g/m ²)	Verticillium disease		Yield, ton/ha			CY ^x (ton/ha)
		Disease incidence ^u (%)	Disease index ^v	Small tubers ^w (< 45 mm)	Large tubers (> 45 mm)	Total weight	
None	None	87.7 a ^y	2.0 a	13	7.1 c	19.9 b	19.7 b
LDPE	50	8.1 c	0.1 c	12	24.0 a	36.2 a	31.3 a
LDPE	25	64.6 b	1.6 b	12	18.2 b	30.2 a	31.0 a
Barromid	25	0.0 c	0.0 c	10	22.7 a	32.3 a	31.9 a
Barromid	15	20.7 c	0.2 c	11	18.0 b	29.4 a	nt ^z

^s Experiment was conducted in commercial plots (8 × 400 m). Potato crop was planted in 5 October 1994, and harvested on 15 February 1995. Tubers were graded for size according to their diameter.

^t LDPE — low density polyethylene; Barromid — gas-tight film.

^u Percent of plants showing disease symptoms.

^v Disease index on a 0 to 3 scale, where 0 = no symptoms and 3 = wilted plants and presence of microsclerotia on the stems.

^w Potato tubers were harvested from a 6-m bed.

^x CY — commercial yield, potato tubers were harvested from the whole plot.

^y Different letters within each column denote significant differences among treatments ($P \leq 0.05$).

^z nt = not tested.

means to reduce MB dosage, such as improved application, and combining this with other methods of control such as solarization, biocontrol agents, disease-tolerant cultivars, or cultural methods, will enable a decrease in MB emission without affecting pest control.

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