Soil Flooding and Fumigant Alternatives to Methyl Bromide in Tomato and Eggplant Production

S.D. Nelson¹

U.S. Department of Agriculture, Agricultural Research Service, Crop Genetics and Environmental Research Laboratory, P.O. Box 110965, Gainesville, FL 32611-0965

S.J. Locascio

Department of Horticultural Sciences, IFAS, University of Florida, P.O. Box 110690, Gainesville, FL 32611

L.H. Allen, Jr.²

U.S. Department of Agriculture, Agricultural Research Service, Crop Genetics and Environmental Research Laboratory, P.O. Box 110965, Gainesville, FL 32611-0965

D.W. Dickson

Department of Entomology and Nematology, IFAS, University of Florida, P.O. Box 110620, Gainesville, FL 32611

D.J. Mitchell

Department of Plant Pathology, IFAS, University of Florida, P.O. Box 110680, Gainesville, FL 32611

Additional index words. 1,3-dichloropropene, chloropicrin, *Meloidogyne incognita*, *Lycopersicon esculentum*, *Solanum melongena*, *Pythium aphanidermatum*, *Pythium myriotylum*

Abstract. Methyl bromide (MeBr) is an important and effective soil fumigant commonly used to control weeds and soilborne pests. Because MeBr has been implicated as a contributor to the depletion of stratospheric ozone, it is scheduled for phaseout by 2005. This study examined nonchemical and chemical practices as alternatives to MeBr. Off-season flooding followed by a series of soil preplant chemical treatments [MeBr with 33% Pic; 1,3-D mixed with 17% (C-17) and 35% (C-35) Pic combined with Peb; and metam-Na combined with 1,3-D and Peb] were evaluated on spring tomato (*Lycopersicon esculentum* Mill.) and eggplant (*Solanum melongena*) production in northern Florida. Pest control and tomato and eggplant yields were not significantly different between the flooded and non-flooded control plots. The most effective alternatives to MeBr were 1,3-D and Pic mixtures (C-17 and C-35) combined with Peb. Tomato and eggplant yields for these chemicals were statistically equivalent to that of MeBr. Tomato, but not eggplant, yield and nematode control were poor with metam-Na combined with 1,3-D and Peb in comparison to the other fumigant combinations. Chemical names used: 1,3-dichloropropene (1,3-D); trichloronitromethane [chloropicrin (Pic)]; S-propyl butyl(ethyl)thiocarbamate [pebulate (Peb)]; sodium N-methyldithiocarbamate (metam-sodium (metam-Na)).

Received for publication 31 July 2001. Accepted for publication 2 Jan. 2002. Florida Agricultural Experiment Station Journal Series R-07893. We thank Wayne Wynn, Andy Frenock, Mike Alligood, and Tom Hewlett, U.S. Dept. of Agriculture, Agricultural Research Service (USDA/ARS), and Univ. of Florida employees for technical assistance. We express gratitude to Jim Ralles (San Francisco) and Klerk's Plastics (Hoogstraten, Belgium) for generous donation of Hytibar film. Mention of trade names or proprietary products is for the convenience of the reader only, and does not constitute endorsement or preferential treatment by USDA/ARS or the Univ. of Florida.

¹Current address: Texas A&M Univ.—Kingsville, MSC 156, 700 University Blvd., Kingsville, TX 78363; e-mail address: kfsdn00@tamuk.edu

²E-mail address: lhajr@gnv.ifas.ufl.edu

Methyl bromide is a widely used agricultural soil fumigant, effective in the control of weeds and soilborne pests. Studies linking MeBr to stratospheric ozone depletion (Wang et al., 1997; Yagi et al., 1995) have resulted in international agreement to ban the manufacture and use of this compound. The impending phaseout of MeBr by the year 2005 in the United States has led researchers to find a viable replacement for this soil fumigant in agricultural production systems (Wang et al., 1997).

One proposed nonchemical alternative is off-season flooding, which can be effective on organic soils (Rhoades, 1964; Snyder, 1987). In past studies, flooding of peat and mineral soils reduced nematode populations and suppressed weed seed viability and disease (Fishler

and Winchester, 1964; Thames and Stoner, 1953). Sotomayor et al. (1999) used mineral soils in small-scale microplots to simulate flooded and non-flooded environments over a 12-week period during 1996 and 1997. In both years soil flooding resulted in reduced root-knot nematode (RKN) [*Meloidogyne incognita* (Kofoid and White) Chitwood] populations 3- to 9-fold compared to non-flooded plots. Also, RKN populations were zero in several high water table experimental field sites at the Univ. of Florida's Indian River Research and Education Center at Ft. Pierce (D.R. Sotomayor, personal communication, 1997). The promising results from the microplot study, and the fact that as much as 20% of Florida soils could be flooded periodically during a portion of the year (Sotomayor et al., 1999), resulted in our interest in conducting the large-scale study presented here.

In addition to soil flooding, the efficacy of various chemical alternatives to MeBr for pest control is being studied in vegetable crop production systems. Previous studies with chemical alternatives to MeBr have produced inconsistent results (Noling and Becker, 1994). More trials are needed to better understand these inconsistencies and improve on potential chemical formulations (Hickey, 1986). Some of the most promising preplant chemical alternatives to MeBr are 1,3-D or Telone combined with 17% or 35% (C-17 or C-35) Pic (Locascio et al., 1997). One chemical mixture that has not been explored is metam-Na combined with 1,3-D and Peb. In the past, metam-Na has led to variable control of soilborne pests in Florida vegetable trials (Locascio et al., 1997); however, the combined use of chemical herbicides and soil fumigants may provide broader-spectrum pest control and greater crop yields.

The objectives of this study were to: 1) evaluate the effectiveness of off-season, short-term soil flooding for control of plant diseases, RKN, and purple (*Cyperus rotundus* L. CYPRO) and yellow nutsedge (*Cyperus esculentus* L. CYPES) in a mineral soil; and 2) evaluate several chemical alternatives to MeBr in tomato and eggplant production in conjunction with preplant flooding and nonflooding of the field. The effects of flooding followed by soil chemical treatments were evaluated for crop yield and control of plant fungal diseases, weeds, and plant parasitic nematodes.

Materials and Methods

Field site preparation. A field site mapped as Millhopper fine sand (loamy, hyperthermic Grossarenic Paleudult) at the Univ. of Florida Horticultural Research Unit in Gainesville was selected. Soil samples were taken at random throughout the field, air dried, passed through a 2.0-mm mesh sieve, and analyzed for initial soil physical conditions and nutrient status before field preparation. This experimental soil had very low salinity, little organic matter, and was slightly acidic (Table 1).

The field site was arranged as a randomized split plot design. The site was randomly

Table 1. Soil physical properties² and nutrient status of a Millhopper fine sand (loamy, hyperthermic Grossarenic Paleudult) prior to project initiation located at the Univ. of Florida Horticultural Research Unit in northwest Gainesville.

ρ_b (g·cm ⁻³)	EC (dS·m ⁻¹)	OM (%)	pH	Ca	Mg	Na	NH ₄ -N mg·kg ⁻¹ soil	NO ₃ -N	P	K
1.6	<0.1	1.0	6.3	504.0	52.4	3.8	2.4	1.2	77.8	38.7

²Symbols and characters used in table: ρ_b = soil bulk density; pH = $-\log_{10} [H^+]$; EC = electrical conductivity; OM = organic matter; NH₄⁺ and NO₃⁻ can be determined by multiplying NH₄-N by 1.29 and NO₃-N by 4.43.

divided into eight sections (16 × 27 m each) with two mainplot treatments, flooded and non-flooded, and replicated four times. Mainplots were further divided into split plot treatment with five randomized treatment rows and two outer buffer rows within each mainplot. The flooded areas were created by forming berms (1.0 m wide × 0.75 m high) around the perimeter of the plot. These berms were covered with a polyethylene plastic film to prevent water erosion and contain surface water within the flooded plot area. A trench was also dug to a depth of 0.75–1.0 m along the sides of the plots adjacent to and between non-flooded plots. A 10-cm-diameter perforated drainpipe with fabric sock covering was placed to a minimum depth of 0.75 m within the trench to increase drainage and to minimize lateral flow into the non-flooded plots. This drainage pipe was extended 250 m downslope from the south edge of the field site to drain the water away from the experimental plots. The sidewall of the trenches adjacent to the non-flooded plots were lined with polyethylene plastic and tucked beneath the drainpipe as additional protection against lateral water movement from flooded to non-flooded plots.

Off-season flooding. Flooded plots received 3 weeks of flooding (starting 16 Nov. 1998), 5 weeks of drying, followed by 3 weeks of flooding (starting again 5 Jan. 1999). Two weeks after termination of each flooding event, all plots were rototilled, and care was taken to not cross-contaminate plots with the rototiller equipment. The purpose of intermittent drying was to promote nutsedge growth and its subsequent destruction by rototilling. An 18-cm head of water was maintained throughout the flooding period by float valves that regulated the water supply from a 5-cm pipe delivery system. Soil anaerobic conditions in flooded plots was monitored with oxidation-reduction potential probes (Cole-Palmer Instrument Co., Vernon Hills, Ill.), and a reference hydrogen electrode correction factor was included to calculate the appropriate millivolt (mV) reading. Aerobic conditions in adjacent non-flooded plots were monitored using 5-cm o.d. (4.5-cm i.d.) plastic well points with slotted walls. A total of five well points were installed in each non-flooded plot to a depth of 0.8 m. A tape measure was used to determine water table depth in each well.

The number of live, soilborne nematodes was determined before and after each flooding. Soil cores were taken before and after the first flooding (16 Nov. 1998 and 5 Jan. 1999), after the second flooding (5 Feb. 1999), and before soil fumigation (18 Feb. 1999). Two sets of 12 soil core samples (2.5-cm diameter,

30 cm deep) were taken randomly from each plot, mixed thoroughly, and nematodes were extracted from a 100-cm³ subsample from each bag by a centrifugal-floatation method (Jenkins, 1964). The calculated number of nematodes per plot was obtained by taking the average of the two sample sets from each plot area.

Plant bioassay of plant parasitic root-knot nematodes was performed using cucumber (*Cucumis sativus* L.) grown under regulated greenhouse conditions of 20 to 35 °C. Six 15-cm-diameter soil cores were taken in 15-cm sections to a depth of 0.9 m from five random locations in each plot following the two flooding events (5 Jan. and 5 Feb. 1999). Soil from each sample was mixed, placed in 18-cm pots to a depth of 15 cm, and two cucumber seeds were allowed to sprout and grow for a period of 75 d. Afterward, cucumber roots were rinsed and root galls were counted after visual evaluation and use of a microscope.

Field studies after flooding. Raised beds (0.9 m wide × 15 m long) were shaped and centered within each mainplot for subplot chemical treatments and to create buffer rows. A broadcast application of 10N–4.4P–8.2K (840 kg·ha⁻¹) fertilizer was rototilled into the beds. Preplant chemical treatments applied on 18 Feb. 1999 included: 1) 67% MeBr + 33% Pic at 392 kg·ha⁻¹ (MeBr-Pic); 2) C-17 at 327 L·ha⁻¹ plus 4.5 kg Peb·ha⁻¹ (C-17); 3) C-35 at 327 L·ha⁻¹ plus 4.5 kg Peb·ha⁻¹ (C-35); 4) metam-Na at 300 L·ha⁻¹ plus 1.3-D at 112 L·ha⁻¹ plus 4.5 kg Peb·ha⁻¹ (metam-Na), and 5) an untreated (control) row. These five treatments were applied to individual beds within each replicate mainplot (flooded, non-flooded) treatment. Metam-Na and Peb were sprayed on the soil surface of designated rows and tilled into the rows before fumigation and covering of beds with polyethylene. Although metam-Na is often applied via sprinkler irrigation systems or drip irrigation lines, we applied the chemical directly to the bed surface to minimize pesticide application outside of the raised beds. The other fumigants were injected under black polyethylene mulch (0.038 mm thick) to a depth of 30 cm with three chisels spaced 35 cm apart. There was one bed for each soil treatment in each of the four reps within each flooding and non-flooding treatment. Just before mulch placement, drip irrigation tubing was placed at the center of the bed for irrigation and fertigation. Beds were fertilized weekly for 10 weeks through the drip lines with a mixture of 14 kg N as NH₄NO₃ and 11.7 kg K as KCl·ha⁻¹ for a season total of 224N–37P–186K kg·ha⁻¹.

On 24 Mar. 1999, thirty 'Florida 47' to-

mato seedlings were transplanted per bed at a spacing of 0.45 m. At the south end of each row, five eggplant seedlings were also transplanted at the same spacing. Nutsedge densities were determined with a 0.1-m² template placed three times at random along each row. Eggplant and tomato plants were inspected weekly for disease, and moribund and dead plants were brought to the lab for pathogen identification. Eggplants and tomatoes were harvested and weighed three times (3, 15, and 24 June 1999). Tomatoes and eggplants were separated using a rolling mechanical fruit-diameter separator into marketable (extra-large, large, medium) and unmarketable fruit classes.

After harvest, six tomato plants per row were dug and roots were visually rated for percentage of root system with RKN, galls, and root rot (caused primarily by *Pythium aphanizematum* and/or *P. myriotylum*), and blight (caused by *Sclerotium rolfsii*). A root system completely galled or dead was given a rating of 100% galled (Barker, 1985) or rotted. Three eggplant plants were removed and evaluated for RKN and root rot using the same rating methods.

Data analysis. Data were subjected to analysis of variance (ANOVA) using the general linear model procedures of SAS (SAS Institute, Cary, N.C.). A randomized split plot design was used, and mainplot (flood/no-flood) and subplot (chemical) treatment means were separated using Duncan's multiple range test (Freund and Little, 1981). The mainplot × subplot interactions were nonsignificant. Preliminary ANOVA comparisons between transformed and untransformed percentage data show no differences; hence all reported results are from untransformed data.

Results and Discussion

Off-season flooding. Flooding resulted in reduced soil redox potential, indicating a change from aerobic to anaerobic conditions (Fig. 1). The redox potential in flooded plots decreased from a well-oxygenated system (>400 mV) during a 2-week period before leveling off at -200 mV, indicating a highly anaerobic environment (Stolzy et al., 1960). Within 4 d of drainage, however, redox potential increased rapidly, indicating a rapid return to aerobic conditions (Fig. 1). Maintenance of aerobic conditions was confirmed in adjacent non-flooded plots by monitoring soil redox in these plots. The water table level within the non-flooded plots remained below the plow layer (0.3-m depth) in all water well points throughout the flooding cycle (data not shown).

Before flooding, numbers of juvenile RKN were statistically similar in flooded and non-flooded plots (Table 2), and interactions between mainplot and subplot treatments were statistically nonsignificant. After the first flooding, nematodes were not detected in the flooded plots, and only 10 nematodes per 100 cm³ soil were found in the non-flooded plots. The majority of cucumber plants from the plant bioassay did not have any root galls, as only two

Fig. 1. Redox potential expressed in millivolts (mV) from oxidation-reduction potential probes placed within flooded plots during two 3-week flooding events followed by drainage. Flooding was initiated on 16 Nov. 1998 for the first cycle and on 5 Jan. 1999 for the second cycle. Data shown represents the mV reading of probes and using a correction factor for a standard hydrogen electrode. Error bars are $\pm$ standard error of the mean.

Table 2. Effects of flooding over time on numbers of root-knot nematode juveniles (*Meloidogyne incognita*) in the upper 30 cm of soil at the Univ. of Florida Horticultural Research Unit in Gainesville.

Mainplot treatment	Root-knot nematodes per 100 cm ³ soil ^a			
	Before flooding	After 1st flooding	After 2nd flooding	Before fumigation
Date sampled	16 Nov. 1998	5 Jan. 1999	5 Feb. 1999	18 Feb. 1999
Non-flooded	133 a ^y	10 a	10 a	12 a
Flooded	69 a	0 b	2 a	2 b

^aCentrifugal-floatation method for plant-parasitic nematode analysis (Jenkins, 1964).

^yMean separation (n = 4) within columns by Duncan's multiple range test, $P = 0.05$.

Table 3. Marketable tomato (Tom) and eggplant (Egg) fruit yields, nutsedge density counts, root-knot nematode root-gall ratings, and root-rot fungal disease ratings. Study performed at the Univ. of Florida Horticultural Research Unit in Gainesville.

Off-season soil-moisture treatments ^a	Marketable fruit yield (t ha ⁻¹)		Nutsedge density (weeds/m)	Root-knot nematode ^b % roots galled	Root rot fungi ^c % root rot
	Tom ^w	Egg			
Non-flooded ^d	42(3)a	28(2)a	74(23)a	22(6)a	18(8)a
Flooded	44(3)a	25(2)a	42(10)a	20(4)a	18(6)a

^aRoot-knot gall ratings assessed by visual inspection.

^bBased on root isolating and pathogenicity tests, root rot was caused predominantly by *Pythium aphanizematum* or *P. myriotylum*; percentage of root system rotted was determined by visual determination (Barker, 1985).

^cFlooded treatments included a 3-week flooding, 5-week dry down, followed by a second 3-week flooding.

^wMean separation (n = 20) within columns by Duncan's multiple range test, $P = 0.05$. Numbers in parentheses are the standard error of the mean.

^dPooled across chemical treatments.

plants from the surface 30 cm of soil from the non-flooded plots resulted in one and two root galls per plant. In fact, the large majority of the soil samples collected had no live nematodes from both the non-flooded and flooded plots, suggesting that a fallow treatment, with or without flooding, reduced juvenile nematode populations during winter months. Thus, the RKN population was anticipated to be very low during the spring cropping. However, nematode numbers were very high in the soil from non-chemically treated beds after spring harvest (100–350 J2 RKN per cm³ soil) regardless of soil flooding. This may indicate

that although elevated soil moisture levels and low winter temperatures may suppress juvenile nematodes, the egg stage of the nematode can survive these harsh conditions.

Flooding did not affect total tomato and eggplant marketable fruit yields, nutsedge counts, or RKN and root rot ratings (Table 3). Although not statistically significant, nutsedge densities were generally lower in flooded plots compared to non-flooded plots. Nevertheless, the high density of nutsedge in the flooded plots not receiving chemical control suggests that flooding alone is not a viable control practice. Herbicides in combination with some

of the alternative soil fumigants may be necessary to control noxious weeds like yellow and purple nutsedge.

Plant growth and yield. In contrast to flooding, fumigant treatment significantly increased eggplant and tomato yield (Table 4). Marketable yields of tomatoes were statistically equivalent among MeBr-Pic, C-17, and C-35 treatments, but were reduced in metam-Na + 1,3-D + Peb or untreated control treatments. Tomato plants in untreated plots, whether flooded or non-flooded, were shorter and less vigorous than tomato plants in chemically treated plots (data not shown). Root-knot galling and root rot indices were two to four times greater in non-fumigated than fumigated rows (Table 4). Isolations from dead or diseased plants indicated that root rot, caused by *Pythium aphanizematum* or *P. myriotylum*, or blight, caused by *Sclerotium rolfsii*, accounted for most of the root and stem damage. The thick density of nutsedge in untreated and metam-Na treated rows may have resulted in decreased tomato growth rate (Table 4), most probably due to increased light and nutrient competition.

Nutsedge weed, RKN, and fungal root rot control in the MeBr-Pic, C-17, C-35, and metam-Na treatments were statistically lower than the control (Table 4). The low pest levels in these plots are probably the main reason why tomato and eggplant marketable yields were greater than the control, and similar between the chemically treated plots. Pest control and fruit yields for 1,3-D plus 17% and 35% Pic treatments were equivalent to that of MeBr-Pic, suggesting that these chemical combinations may be suitable replacements for MeBr in Florida tomato production systems. Reduced tomato yields in the metam-Na + 1,3-D + Peb treatment suggest that this mixture may be a less effective fumigant combination in polyethylene mulch tomato production. However, a different metam-Na application method other than soil surface spraying and rototill used in our study could provide more effective pest control. Regardless, maximum yields of tomato and eggplant will require adequate nematode, fungi, and weed control in spring Florida vegetable production.

Summary. The results from this study indicate that short-term (3 weeks) soil flooding in winter does not control pests and weeds in well-drained mineral soils of north-central Florida. However, soil flooding should be evaluated over longer time periods and over several growing seasons to estimate its potential. Longer anaerobic or summertime flooding may provide greater pest control (Sotomayor et al., 1999).

This study indicates that the most promising replacement for MeBr in northern Florida vegetable production is likely to be a concerted use of soil fumigants and herbicides for adequate pest control and crop yields. The fumigants C-17 or C-35 plus Peb provided pest control and vegetable yields similar to that of MeBr-Pic. The use of metam-Na, surface applied and rototilled, coupled with 1,3-D and Peb, provided similar pest control, but lower tomato yields than MeBr-Pic. It is rec-

Table 4. Marketable tomato (Tom) and eggplant (Egg) fruit yields, nutsedge density counts, root-knot nematode root-gall ratings, and root-rot disease ratings as influenced by pre-plant fumigant and herbicide treatments. Study performed at the Univ. of Florida Horticultural Research Unit in Gainesville.

Fumigant ² treatment	Rate (kg ha ⁻¹)	Marketable yield (t ha ⁻¹)		Nutsedge weeds/m	Roots ^y galled (%)	Root ^x rot (%)
		Tom ^y	Egg			
None	0	28(3) c	21(2) a	150(54) a	56(15) a	28(3) a
MeBr-Pic	392	52(2) a	30(3) b	14(5) c	11(3) b	14(3) b
C-17+Peb	327L ^w + 4.5	49(3) a	29(4) b	22(8) c	12(3) b	17(2) b
C-35 + Peb	327L + 4.5	47(4) a	26(3) b	8(6) c	14(3) b	16(3) b
Metam-Na +	300L +	39(3) b	26(3) b	80(39) b	10(3) b	15(2) b
1,3-D + Peb	112L + 4.5					

²Fumigant treatment legend: methyl bromide (MeBr); chloropicrin (Pic); 1,3-dichloropropene (1,3-D); pebulate (Peb); and metam sodium (Metam-Na).

^yRoot-knot gall ratings performed by visual inspection.

^xBased on root isolating and pathogenicity tests, root rot was caused predominantly by *Pythium aphanizematum* and *P. myriotylum* and percentage of root system rotted was performed by visual determination.

^wFumigant rates not in kg ha⁻¹ are shown in liters (L) per hectare.

^yMean separation (n = 8) within columns by Duncan's multiple range test, *P* = 0.05. Numbers in parenthesis are the standard error of the mean.

ommended that continued research be placed upon these chemicals so that their long-term agricultural use can be further evaluated. This study demonstrates that acceptable crop yields in Florida require adequate control of fungal diseases, nematodes, and weeds, especially purple and yellow nutsedge.

Literature Cited

Barker, K.R. 1985. Nematode extraction and bioassays, p. 19–35. In: K.R. Barker, C.C. Carter, and J.N. Sasser (eds.). An advanced treatise on

meloidogyne. vol. II. Methodology. U.S. Agency Intl. Dev., Raleigh, N.C.

Fishler, D.W. and J.A. Winchester. 1964. The effects of flooding on root-knot nematodes in organic soil. Soil Crop Sci. Soc. Fla. Proc. 24:150–154.

Hickey, K.D. (ed.). 1986. Methods for evaluating pesticides for control of plant pathogens. APS Press, St. Paul, Minn.

Freund, R.J. and R.C. Little. 1981. SAS for linear models. SAS Inst., Cary, N.C.

Jenkins, W.R. 1964. A rapid centrifugal-floatation technique for separating nematodes from the soil. Plant Dis. Rpt. 48:692.

Locascio, S.J., J.P. Gilreath, D.W. Dickson, T.A. Kucharek, J.P. Jones, and J.W. Noling. 1997. Fumigant alternatives to methyl bromide for polyethylene-mulched tomato. HortScience 32:1208–1211.

Noling, J.W. and J.O. Becker. 1994. The challenge of research and extension to define and implement alternatives to methyl bromide. J. Nematol. 26:573–586.

Rhoades, H.L. 1964. Effect of fallowing and flooding on root-knot in peat soil. Plant Dis. Rpt. 48:303–306.

Snyder, G.H. (ed.). 1987. Agricultural flooding of organic soils. Agr. Expt. Sta. Tech. Bul. 870. Univ. of Florida, Gainesville.

Sotomayor, D., L.H. Allen, Jr., Z. Chen, D.W. Dickson, and T. Hewlett. 1999. Anaerobic soil management practices and solarization for nematode control in Florida. Nematropica 29:153–170.

Stolzy, L.H., S.D. Van Gundy, and J. Letey. 1960. Oxygen tolerances of four plant parasitic nematodes. Phytopathology 50:656.

Thames, W.H., Jr., and W.N. Stoner. 1953. A preliminary trial of lowland culture rice in rotation with vegetable crops as a means of reducing root-knot nematode infestations in the Everglades. Plant Dis. Rpt. 37:187–192.

Wang, D., S.R. Yates, F.F. Ernst, J. Gan, and W.A. Jury. 1997. Reducing methyl bromide emission with a high barrier plastic film and reduced dosage. Environ. Sci. Technol. 31:3686–3691.

Yagi, K., J. Williams, N.Y. Wang, and R.J. Cicerone. 1995. Atmospheric methyl bromide (CH₃Br) from agricultural soil fumigations. Science 267:1979–1981.