Methyl Bromide Alternatives – Meeting the Deadlines

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Introduction

Krishna V. Subbarao

Department of Plant Pathology, University of California, Davis, c/o U.S. Agricultural Research Station, 1636 E. Alisal Street, Salinas 93905.

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My assignment for this symposium is to provide a brief commentary on various issues surrounding methyl bromide and aspects of research on the alternatives to methyl bromide in agriculture discussed by the symposium speakers. About 5 years ago, another symposium was held under the aegis of the The American Phytopathological Society that focused on the impact of methyl bromide withdrawal and areas of research in the search for alternatives that were just getting underway. The current symposium is the result of the Soil Microbiology and Root Diseases Committee's decision to take stock of the research on methyl bromide alternatives because the deadline for its withdrawal is drawing closer. As the following papers demonstrate, a multifaceted progress has been achieved in the past 9 years toward not only identifying chemical alternatives and the mode of their applications to reduce emissions, but also toward developing integrated approaches to cushion the losses resulting from methyl bromide withdrawal from soil fumigation.

Issues surrounding methyl bromide. Fumigation has been used as a method of pest control for more than 100 years. Methyl bromide has been used as a fumigant (a chemical that can exist in a gaseous state in sufficient concentration at a given temperature and pressure to be lethal to a given pest or groups of pests) for at least 60 years after its insecticidal properties were first described in 1932 (11). Methyl bromide has become an indispensable fumigant because of its low vapor pressure and broad-spectrum biocidal activity. However, because of its recently understood negative effect on the stratospheric ozone, it has received much attention during the past decade.

Atmospheric methyl bromide is believed to be the principal source of stratospheric bromine. The bromine atom is highly effective in converting ozone to oxygen and is about 60 times more potent than chlorine in destroying stratospheric ozone (7). Reactions involving bromine are believed to be responsible for increasing the "ozone hole" over Antarctica by 20 to 25% each year (3). Because of this efficiency of ozone destruction, characterized as ozone depleting potential (ODP), methyl bromide has been designated as a class I stratospheric ozone depleting substance by the Montreal Protocol (2). The ODP represents the cumulative ozone depletion induced by a particular halocarbon relative usually to a trichlorofluoromethane such as CFC-11. Current

estimates place the ODP of methyl bromide at 0.4, with a range of 0.2 to 0.5 (16).

A great deal of uncertainty still exists about the origins and action of methyl bromide. Its known sources include oceanic emissions, biomass burning, automobile emissions from leaded gasoline, and agricultural and structural fumigation (8). Of these, oceanic emissions and a fraction of the biomass burning emissions are natural. Of the total global emissions of 100 to 200 Gg per year (6), 30 to 65 Gg per year is attributed to agricultural fumigation. The current methods of methyl bromide application for soil fumigation results in approximately 34% escape into the atmosphere (18). Quantification of natural emissions is complicated by the dual role of the ocean acting as both the sink and source of atmospheric methyl bromide. It is both produced and destroyed in the oceans, and the rates of these processes can exert a major influence on atmospheric methyl bromide concentrations (8). Although some studies suggest that oceans are a strong net source of methyl bromide to the atmosphere and the switch from source to sink can occur under certain conditions (15), others have concluded that oceans are a small net sink and that the methyl bromide consumption reactions are sensitive to changes in temperature affecting the exchange between the atmosphere and the ocean (2). Furthermore, soil also can act as a sink, and the global annual soil sink is estimated to be 42 ± 32 Gg (17). Ongoing studies are attempting to resolve the sources and sinks of methyl bromide, determining the proportion of anthropogenic emissions in the overall methyl bromide budget in the atmosphere, assessing the relative contribution of methyl bromide to total stratospheric bromine, and the efficiency of bromine in depleting stratospheric ozone (8).

Methyl bromide use in agriculture and other areas. Before addressing the question of where we are in developing alternatives to methyl bromide, we need to assess the current methyl bromide use in agriculture and other areas. The cumulative worldwide use of methyl bromide for structural, postharvest, and soil fumigation is about 95% of the total; the United States alone accounts for nearly 32% of this total. Of the total worldwide use, about 5% is used for structural, 13% for postharvest and quarantine, and 82% for preplant soil fumigation (5). The largest methyl bromide use in the United States occurs in California and Florida, and concomitant efforts are underway in these two states to search for alternatives. The major preplant soil fumigation in these two states occurs on strawberries and tomatoes, respectively. While research is continuing to address the above questions at a rapid pace, the United States has frozen production and importation of methyl bromide to 1991 levels, with the total production to cease in 2005

Corresponding author: K. V. Subbarao; E-mail address: kvsubbarao@ucdavis.edu

(4). This action has triggered a feverish search for alternatives in agriculture that can perform the broad-spectrum functions of this agricultural and structural fumigant. Developing countries have been permitted to use methyl bromide for soil fumigation until 2015.

Economic impact of methyl bromide withdrawal. Fumigation with methyl bromide is credited with bringing stability and higher economic returns for commodities that depend on it. Methyl bromide withdrawal may potentially render systems that depend on it highly unstable and unpredictable in the short-run. The National Biological Impact Assessment Program (NAPIAP) conducted a benefit analysis and concluded that unless satisfactory substitutes for methyl bromide are found, its loss will have serious negative impact on U.S. agriculture. Depending on the crop, yield losses are estimated to be 13 to 25%. Cancellation of methyl bromide will have two effects on costs in agriculture: soil treatment costs will change and harvest costs will fall due to yield losses or to voluntarily reduced production area (4). In addition, it will result in the loss of markets due to quarantine and phytosanitary requirements. It has been estimated that annual losses in short-term net farm income in California will be more than \$162 million, with strawberries accounting for more than 60% of these losses. Thus, the economic impact will be unevenly distributed by region, with areas growing high value crops such as strawberries bearing a disproportionately larger share of the total losses (19). Similarly, postharvest applications of methyl bromide are critical for many commodities to satisfy the phytosanitary requirements of exporting them. About 95% of the quarantined commodities depend on methyl bromide fumigations and its withdrawal is expected to seriously impede U.S. trade. Similar economic losses are likely in other developed countries that rely on the use of methyl bromide soil fumigation.

The current status of the search for alternatives to methyl bromide. The potential economic loss owing to methyl bromide withdrawal makes research on alternatives a very high national priority. The search for alternatives to methyl bromide has focused on chemical alternatives, refinement of application methods to reduce emissions, biological and cultural controls, and integration of approaches. Hence, the papers presented in this symposium also focus on these aspects. Earlier attempts to develop physical methods such as steam treatment, microwave and other pulsed-power technologies have neither held up to the initial promise nor are economical.

No single registered fumigant or practice has shown the broad-spectrum activities of methyl bromide. Ultimately, we may or may not be able to identify or develop alternative fumigants or practices that are eco-friendly and yet perform the myriad functions of methyl bromide. The manuscript by Duniway (10) provides a comprehensive account of the history of methyl bromide use on California strawberries and the pros and cons of using the different registered chemical alternatives and experimental fumigants. The manuscript further elaborates on chemicals such as Chloropicrin and Telone (1,3-dichloropropene) that provide the broad-spectrum control of soilborne plant pathogens, but their activity on weeds and other volunteers remains a question. Furthermore, concern also exists regarding their toxicity and carcinogenicity to humans. High volatility of Telone threatens worker safety, and poses concern for offsite movement in air and water. Among the alternative fumigants, methyl iodide and propargyl bromide in repeated testing have shown promise as near-complete replacements for methyl bromide judging by their effect on soilborne pests, plant growth promotion, and yield. The availability, production, and responsibility for the enormous task of registration on such diverse crops affected by the methyl bromide withdrawal remain unanswered for both these chemicals. Duniway (10) also discusses the use of mixtures of chemicals or sequential use of these chemicals to attain the level of pest control and yield response similar to those of methyl bromide.

The primary objection to the continued use of methyl bromide is the unrestricted release of the gas into the atmosphere after fumigation. It may therefore be necessary to seek methods of using methyl bromide or other alternative fumigants that prevent escape of the gas or reduce its loss into the atmosphere. These methods, although increasing the time of soil retention and the concomitant efficacy of chemicals, may also lower the amount of fumigants required to achieve desired efficacy. The manuscript by Yates et al. (20) explores factors such as the effects of various plastic films, depth of fumigant application, increasing soil water content to reduce soil porosity, soil bulk density, and organic matter content on volatilization of fumigants. They further discuss the use of certain fertilizers to enhance the soil degradation of methyl bromide to prevent volatilization and escape into the atmosphere. In a related paper, Ajwa et al. (1) discuss the application of water soluble alternative fumigants through drip irrigation to reduce emissions into the atmosphere and worker exposure and to increase the efficacy of fumigants. Furthermore, they discuss the relative merits of various fumigant injection methods and fumigant distribution under different soil conditions, etc. Additional advantages such as the simultaneous or sequential application of the fumigants through drip irrigation systems have been thoroughly examined in this paper (1).

Despite the availability of effective alternative chemicals and application methods, heightened public concern regarding the use of agricultural chemicals is a reality. These concerns may lead to continuing review and increased regulation of the alternative chemicals. These difficulties and the unlikelihood of finding an immediate alternative that can serve as a direct replacement for methyl bromide call for integration of approaches to obtain optimal results. Cultural controls are many and have tremendous potential. Amendments to soil with certain crop residues have shown remarkable disease suppression effects. The manuscript by Martin and Bull (12) discusses the potential for biological control systems in relation to crop rotation, host resistance, and rhizosphere ecology while recognizing these efforts are likely to be successful in the longer term. Even when successful, biological controls as alternatives to methyl bromide will most likely need to be integrated with other control strategies for two reasons. First, the lower level of control is usually unacceptable for high value crops and second, frequently there is a need to meet extensive regulatory requirements. The authors also discuss how an understanding of the microbial community structure of the fumigated soil and applying it to the nonfumigated soils may help alleviate soilborne pathogens. Whereas this paper focuses on the strawberry production system (12), the manuscript by Mazzola et al. (13) focuses on the management of microbial community in a perennial cropping system with a serious replant disease. Mazzola et al. (13) discuss how microbial communities altered by specific wheat cultivars suppress components of the microbial complex responsible for apple replant disease. They further review how specific pathogen suppression by high-glucosinolate containing rapeseed meal can be integrated into the wheat-induced disease suppressive microbial community.

For integrated pest management (IPM) to be an effective alternative for methyl bromide, it will have to be custom tailored for each cropping system. The paper by Chellemi (9) examines the different components of the IPM system and how these components can be integrated in a "proactive" approach to solve problems of specific cropping systems. This will require extensive research and training and may be limited in small, low value crops. Host resistance, cultural, and biological controls will need to be integrated and adapted to each production system to replace methyl bromide. Host resistance is an obvious measure because resistance to many soilborne pathogens is both complete and long lasting. Solarization has already been shown to compare very favorably with methyl bromide in the fall fresh market tomato production in north Florida and for cotton and tomato production

in California. In certain environments, the combination of crop residues and solarization is likely to be an effective disease management strategy. The key here is not only to develop an effective method, but also be able to implement it into the current production systems for rapid acceptance. If major changes in cultural practices are required, the growers may adopt the practices more slowly. At the same time, however, most cultural practices will not need any regulatory consideration, and thus implementation after development can be extremely rapid.

The final contribution by Noling (14) has offered a dispassionate discussion of the practical realities and potential outcomes of the methyl bromide alternatives research to date. In this paper, Noling (14) has reviewed the pros and cons of various chemical alternatives, methods of reducing emissions, soil application technologies, and the various nonchemical approaches. The general pitfalls of transferring the chemical and nonchemical alternatives to different geographic regions affected by methyl bromide withdrawal have also been critically examined.

Although the symposium attempted to provide a comprehensive account of all methyl bromide alternatives research, it is by no means complete. Because of the obvious difficulties in inviting speakers from outside the United States, we were unable to review relevant research efforts in other parts of the world affected by methyl bromide withdrawal. The readers are directed to the proceedings of the annual methyl bromide alternatives research for a more complete picture of research in this area.

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LITERATURE CITED

1. Ajwa, H. A., Trout, T., Mueller, J., Wilhelm, S., Nelson, S. D., Soppe, R., and Shatley, D. 2002. Application of alternative fumigants through drip

- irrigation systems. *Phytopathology* 92:1349-1355.
2. Anbar, A. D., Yung, Y. L., and Chavez, F. P. 1996. Methyl bromide: Ocean sources, ocean sinks, and climate sensitivity. *Global Biogeochem. Cycles* 10:175-190.
3. Anderson, J. G., Brune, W. H., Lloyd, S. A., Toohey, D. W., Sander, S. P., Starr, W. L., Lowenstein, M., and Podolske, J. R. 1989. Kinetics of O₃ destruction by ClO and BrO within the Antarctic vortex: An analysis based on in situ ER-2 data. *J. Geophys. Res.* 94:11480-11520.
4. Anonymous. 1993. Alternatives to methyl bromide: Assessment of research needs and priorities. *Proc. USDA Workshop Alternatives Methyl Bromide*, Beltsville, MD.
5. Anonymous. 1993. The biologic and economic assessment of methyl bromide. The National Agricultural Pesticide Impact Assessment Program (NAPIAP). U.S. Dep. Agric.
6. Anonymous. 1994. Scientific assessment of ozone depletion. World Meteorological Organization, Geneva.
7. Anonymous. 1998. Protecting the ozone layer, vol. 6. Methyl bromide. United Nations Environment Program, Paris.
8. Butler, J. H. 1995. Methyl bromide under scrutiny. *Nature* 376:469-470.
9. Chellemi, D. O. 2002. Nonchemical management of soilborne pests in fresh market vegetable production systems. *Phytopathology* 92:1367-1372.
10. Duniway, J. M. 2002. Status of chemical alternatives to methyl bromide for pre-plant fumigation of soil. *Phytopathology* 92:1337-1343.
11. Le Goupil, P. 1932. Les propriétés insecticides du bromure de methyl. *Rev. Path. Vég. Ent. Agric. France* 19:169-172.
12. Martin, F. N., and Bull, C. T. 2002. Biological approaches for control of root pathogens of strawberry. *Phytopathology* 92:1356-1362.
13. Mazzola, M., Granatstein, D. M., Elfving, D. C., Mullinix, K., and Gu, Y.-H. 2002. Cultural management of microbial community structure to enhance growth of apple in replant soils. *Phytopathology* 92:1363-1366.
14. Noling, J. W. 2002. The practical realities of alternatives to methyl bromide: Concluding remarks. *Phytopathology* 92:1373-1375.
15. Pilinis, C., King, D. B., and Saltzman, E. S. 1996. The oceans: A source or a sink of methyl bromide? *Geophys. Res. Lett.* 23:817-820.
16. Selwyn, M. R., Georges, J. E., and Georgiev, A. A. 1997. Estimating ozone depletion potential of methyl bromide. *Risk Anal.* 17:9-17.
17. Shorter, J. H., Kolb, C. E., Crill, P. M., Kerwin, R. A., Talbot, R. W., Hines, M. E., and Harriss, R. C. 1995. Rapid degradation of atmospheric methyl bromide in soils. *Nature* 377:717-719.
18. Yagi, K., Williams, J., Wang, N.-Y., and Cicerone, R. J. 1995. Atmospheric methyl bromide (CH₃Br) from agricultural soil fumigants. *Science* 267:1979-1981.
19. Yarkin, C., Sunding, D., Zilberman, D., and Siebert, J. 1994. All crops should not be treated equally. *Calif. Agric.* 48:10-15.
20. Yates, S. R., Gan, J., Papiernik, S. K., Dungan, R., and Wang, D. 2002. Reducing fumigant emissions after soil application. *Phytopathology* 92:1344-1348.