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VIEWPOINT

The Challenge of Research and Extension to Define and Implement Alternatives to Methyl Bromide[1]

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Abstract: Over the past 30 years, methyl bromide (MBr), a broad spectrum fumigant, has been used extensively for soilborne disease and pest control in the production of many fruit, vegetable, turf, and nursery crops. Recently, agricultural emissions of MBr were implicated as a potentially significant contributor to stratospheric ozone depletion. As a precautionary measure for global ozone protection, the U.S. Environmental Protection Agency has enforced federal legislation which mandates a complete phase–out of MBr use within the United States by 1 January 2001. Thus, new cost effective, environmentally compatible strategies for control of nematodes and other soilborne pests and pathogens must be developed and tested in a relatively short time to avoid significant losses in crop productivity. The extent to which certain agricultural industries that are now heavily reliant on MBr are affected will depend on the development of sustainable, integrated tactics to pest control, such as combinations of cultural, chemical, and biological tactics. New multidisciplinary research and extension programs must be developed to address and overcome major constraints and incompatibilities that have prevented such tactics from being widely adopted.
Key words: alternative agriculture, biological control, chemical control, cultural control, fumigation, integrated pest management, methyl bromide, nematode, nematode management, sustainable agriculture.

The preplant soil-fumigant, methyl bromide (MBr), is currently used in the production of at least 21 different crops grown in California, Florida, Georgia, North Carolina, and South Carolina to control weeds, plant diseases, plant–parasitic nematodes, and to a lesser extent, soil arthropods (21). Methyl bromide is also widely used as a structural and commodity fumigant, as well as for quarantine or regulatory purposes (105,106,110). In Florida, and in other states, MBr is used most extensively under plastic mulch as a preplant biocidal soil fumigant for increasing production of fruits, vegetables, turfgrasses, and nursery crops, the most important of which are tomato, pepper, and strawberry (21,34,41,65,69,70).

For soil fumigation purposes, MBr is injected 20–30 cm deep as a liquid. It rapidly volatilizes into a gas permeating open soil pore spaces (26,38,48). For most applications, a plastic mulch or tarpaulin soil cover is used mandatorily after injection to retard soil dissipation and enhance pesticide efficacy (38,48,65).

Environmentally, the problem with MBr is that upward mass flow and diffusion is usually greater than downward movement. In most cases, the plastic mulch soil cover only serves to retard atmospheric release of MBr. Although estimated with some uncertainty, as much as 30–60% of the MBr applied to soil may escape the

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plant bed (110). The wide range in plant bed losses of MBr is due to the permeability of the plastic mulch cover and to the range of cultural practices and environmental conditions occurring at the time of soil fumigation (26,38,48).

The emission of MBr into the atmosphere is critically important because the most recent environmental assessments have concluded that bromine is one of the chemicals largely responsible for global ozone depletion (110). These same scientific assessments conducted under the Montreal Protocol, an international agreement among 128 countries to review and limit substances that deplete the ozone layer, identified MBr as a potentially significant contributor to stratospheric ozone depletion. Many different sources for atmospheric MBr have been identified, including natural oceanic sources, the burning of leaded gasoline and biomass, as well as from other anthropogenic sources, such as soil, structural, and commodity fumigation (11,16,45,110).

In 1993, the Montreal Protocol treaty was amended to require developed countries by 1995 to freeze the production and use of MBr at 1991 levels. The U.S. Environmental Protection Agency (EPA) has taken a more stringent precautionary measure by enforcing the Clean Air Act of 1990, which mandates a complete phase-out of MBr use by 1 January 2001 (107). There is also a possibility that a substantial federal excise tax on ozone-depleting substances will be levied in an attempt to further restrict MBr use. Unfortunately, the Clean Air Act, as currently written, does not allow for any exemption for continued MBr use even though it may be possible to reduce emissions to potentially nonproblematic levels (58), or that natural oceanic source production may increase to buffer any change from soil fumigation emissions (11).

As extension nematologists, it is our responsibility to develop and implement new, practical, management strategies for plant-parasitic nematodes considering a diversity of crops, environments, production systems, and pest complexes. Growers expect us to provide these alternative strategies on demand, particularly in time of need. With the impending loss of MBr, new environmentally-compatible strategies for pest control must be developed, in a relatively short time, to avoid significant losses in crop productivity due to a broad complex of soilborne plant pests and pathogens. The cost to growers and consumers resulting from the suspension of MBr for soil fumigation purposes alone is expected to be at least $1 billion annually (21).

Given the current lack of equally effective alternatives to MBr suggests future limitations to broad-spectrum control of many different soilborne pests and pathogens and a real potential for significant yield losses (105,106) and (or) increased production costs (5,21,54). Our objectives are as follows: i) to review how MBr came into such extensive use; ii) to discuss its effectiveness and identify incompatibilities of currently identified pest control alternatives; and iii) to discuss informational constraints to new technology transfer and grower adoption. This document may also be used to provide guidance for nematological research on alternatives to MBr.

Historical Development and Use of Methyl Bromide

Before 1950, vegetable and strawberry culture in Florida and California can best be described as nomadic. One to four successive crops were produced on rented land after expensive clearing operations had been performed or after long pasture rotations to avoid soilborne pest and disease problems (7,34,68,115). As urban growth increased, suitable land for crop production became more difficult to locate and expensive to acquire and develop (69). Because of these constraints, growers increasingly adopted chemical methods of soil pest management (primarily for weeds, nematodes, and diseases). Reverting to such a production system is no longer a viable option because of the unavailability of suitable land, as well as other environmental and water management regulatory policies.

During the early to mid–1950s, various soil fumigants became available for testing and use in an attempt to resolve nematode and disease problems that developed in continuously cultivated fields (30,34,38,68, 113–115). These new soil fumigants not only alleviated some of the problems, but allowed growers to use the same fields for vegetable or strawberry production each year, taking advantage of their financial investment in property, land improvements, and site location (7,65).

In the late 1950s, nonfumigant nematicidal chemicals became available for field testing (30). Although some showed promise for certain pests or specific complexes, none proved equal to MBr, i.e., one which possessed herbicidal, fungicidal, and nematicidal properties. Unlike MBr, some left toxic residues in the soil for an unacceptable period or posed potentially serious environmental risks to surface or groundwater.

Since 1960, MBr or MBr-chloropicrin formulations (69,115) were rapidly adopted, almost to the exclusion of other chemical pest control methods for many different fruit and vegetable crops. This occurred primarily because MBr soil fumigation provided superior broad-spectrum control of plant-parasitic nematodes, soil pests and disease pathogens. This generally translated into superior vegetative plant growth and yield, and more uniform fruit maturity, such that harvesting could be completed in fewer pickings at lower total cost. Unlike most other chemical alternatives, MBr treatment requires reduced soil aeration periods before planting, thus posing little risk of crop phytotoxicity. The availability of a reliable, economical, preplant soil fumigant, such as MBr, was a critical factor in the development of different high value multiple cropping systems (7,21), which could be reduced or lost with alternative substitutes (21).

The Challenge to Define Alternatives

Presently, a number of chemical and nonchemical approaches are available for nematode control, and each will be discussed separately. Although extremely important, the efficacy of these approaches against other soilborne diseases and pests is outside the scope of this discussion. Cultural control methods for nematode population suppression include the use of soil amendments, cover crops and resistant varieties, flooding, solarization, or bare fallowing (15,18,33,46,49–51,60,79,83,85,94, 104). Where practical and appropriate, many of these practices are integrated into the 'off-season' cropping sequence. Unlike the 'quick kill' efficacy of MBr, these methods tend to reduce nematode population densities gradually.

Nonchemical Alternatives

Bare fallow: In most production agriculture systems, fallowing is currently used to a limited degree during the period between successive crops to reduce soil nematode population densities. Unfortunately, the fallow period is often defined as the period before planting when fields are being prepared for the next crop to ensure seedbed tilth and uniform soil moisture conditions. In actuality, the most appropriate time to fallow comes immediately after final crop harvest when most farm equipment is committed exclusively to ongoing harvesting operations. Lengthly delays in crop destruction probably contribute to greater nematode population increase and greater difficulty in achieving nematode control. Fallowing, of even short duration, when coupled with crop root destruction generally gives significant and immediate impact on total nematode population densities in soil (32,37,67,74,75). Under some conditions, fallowing has been equivalent or superior to cover cropping or crop rotation as a means of nematode population suppression (37).

Unfortunately, fallowing has unfavorable effects on soil organic matter, soil structure, and potential for enhanced soil erosion (10). Because of the wide host range of many nematode species, uncontrolled weed growth during the fallowing period can also mitigate its suppressive effect on nematode soil populations (51,67, 71). Frequent tillage is generally required to maintain clean fallow soil conditions.

Cover crops: Use of cover crops is another nonchemical tactic that reduces nematode population densities (12,32,74,75,78,85, 89,117). Many cover crops have been evaluated, including legumes (84,86), small grains (87), and pastureland grasses (88). Many of these crops provide benefits to crop production other than nematode suppression. For example, sorghum suppresses root-knot nematode populations and restores large amounts of soil organic matter. Recent studies in Florida and Alabama have shown that several tropical perennial legumes effectively reduce some plant-parasitic nematodes, even after a single cropping cycle (43,85,86). Exclusion of weeds that host nematodes and problems encountered with stand establishment of some cover crops must be resolved, however, if this approach is to be used reliably.

Crop rotation: Crop rotation with poor or nonhost crops is another effective means of reducing soil population densities of nematodes (3,36,60,84,103). In many cases, the major constraints to the use of crop rotation involve the broad host range of many economically important nematodes, occurrence of several nematode species in a given production field, lack of available resistant or tolerant cultivars, or the lack of agronomically adapted cultivars (91,102). Crop rotation may also fail to reduce nematode densities below economically damaging levels (31,36,78,85). In this case, either the crop rotation period must be extended or other practices must be integrated to control nematodes.

Nonhost crops may reduce average annual farm revenues, particularly if the crops have little cash value and (or) have low regional marketability (40,49,50,85, 100). In a rotation program, the sequence of crops must be economically attractive to the grower, providing marketable crops that produce some form of income or means for production cost recovery. Frequently, the developers of alternative cropping strategies do not seriously consider the costs to production and reductions in average annual farm revenues (20,52). Most crop rotation evaluations, in fact, have been performed on low value agronomic crops for which chemical soil treatments are not economical.

Growers have developed crop specialization niches to avoid market competition, to take advantage of suitable geographic, soil, and environmental growing conditions, and to minimize capital investments in machinery and labor requirements. Crop rotation has been ignored by some growers because of limited land availability (3) or because of marketing constraints (40,85). In many cases growers do not possess the managerial skills needed to produce a wide range of crops.

As useful as crop rotation, cover cropping, and fallowing can be for nematode management, they have a number of disadvantages that must receive additional research emphasis before widespread adoption can be expected. New quantitative approaches, as proposed by Noe (52), could serve as a starting point for evaluation and development.

For nematodes with limited host ranges, crop rotation has been used successfully as a management tactic. It is not always clear whether crop rotation will be sufficient to allow economic production of a subsequent susceptible crops (31,36,37,85). In some cases, rotations incorporating poor-host graminaceous crops may not reduce root-knot nematode population densities below damaging levels (78). In other cases, effective crop rotations cannot be economically used without a change in farm enterprises system diversity (i.e., use of forage legumes or pastureland grasses) (49,50).

Soil amendments: Use of soil amendments for nematode population suppression has remained largely unexplored in commercial vegetable production. Organic and inorganic amendments have been applied to soil to suppress populations of plant-parasitic nematodes and to increase crop yield (1,46,75,83,112). Chitin and inorganic fertilizers that release ammoniacal nitrogen into soil suppress nematode population densities due to plasmolyzing effects and to selective proliferation of microbial antagonists (83). The high rates required for nematode control by most organic amendments (metric tons per ha), the high rates of oxidation due to high soil temperature and moisture conditions (10), their high costs, and their marginally defined efficacy are major limitations that have constrained expanded use of these materials.

Soil amendments and other composted materials can contribute greatly to soil tilth, fertility, water-holding capacity, and soil antagonistic potential (94), thus it is important that research continues to integrate this tactic with other cultural, biological, and chemical nematode management strategies.

Biocontrol: Soil amendments, to encourage the activity of indigenous soil microbes, are one form of biological control by which a multitude of natural enemies suppress plant-parasitic nematodes. However, commercial development of biological control will probably depend on the development of one or more microbial strains that can be applied to the soil or plant rhizosphere (35). At present, there are no effective nematode biological control agents that can be successfully integrated into a vegetable crop management program, even though some products are commercially available (39). There is a distinct need to continue the search for and evaluation of potential biocontrol agents and (or) natural products for management of soilborne nematode and disease problems. However, their commercial development will depend on overcoming many scientific, economic, and conceptual hurdles (6).

Plant resistance: Use of nematode-resistant crop cultivars is often viewed as the foundation of a successful integrated nematode management program on all high value crops in which MBr is currently used (105,106). However, the development and use of resistant cultivars occurs mainly in relatively low value agronomic crops, such as potato and soybean. This is not surprising given the marketing opportunities for seed producers associated with large hectarage crops. In addition, the availability of these resistant cultivars is often the only economic recourse to growers of low value crops for nematode management (85).

In contrast, research progress toward the development of nematode resistant high value crop cultivars has been slow. Commercial nematode–resistant cultivars of vegetable crops are currently only available for tomato, southern pea, pepper, bean, and sweet potato. Ironically, this has probably been the result of satisfactory alternative control measures, such as MBr (17).

With the impending loss of MBr, new sources of resistance must be identified and used to develop new cultivars as rapidly as possible, with simultaneous consideration of appropriate marketing and horticultural characteristics (100,105,106). The combination of these attributes will ultimately dictate grower acceptability and use. The recent discovery of plant genes that are turned on by *Meloidogyne* spp. feeding may revolutionize the development of new resistant crops (8,62). New, concerted research efforts are likely to be required to manage this pool of new resistant cultivars to control the emergence of resistance-breaking races (17,77,79,82, 116), or undesirable nematode species shifts (85,111).

Further constraints and problems to immediate use of some of the currently available resistant cultivars should also be considered. For example, in tomato, a single dominant gene for resistance to *Meloidogyne incognita* has been introduced into a relatively large number of tomato cultivars (80,91). In some cases the resistance has failed as a result of the heat instability or apparent temperature sensitivity of the resistance gene (17,47,61). In some geographical regions use of these cultivars may have to be restricted to spring plantings when cooler temperatures prevail (17). It also may be necessary to consider eliminating the use of black plastic mulch, which will pose other problems, particularly in Florida, where plastic mulch is an integral component of pest and crop management programs (66).

Flooding: Flooding is another management tactic that has been used to suppress plant–parasitic nematode population densities (64,76). Alternating cycles of flooding and drying have proven to be more effective than continuous flooding (64). Based on the current attitudes concerning water conservation and increased urban demand, it is unlikely that water management agencies will allow or continue to permit flooding in regions where the tactic is feasible.

Soil solarization: Soil solarization, covering moist soil with clear plastic, is a nonchemical soil pest management practice that has reduced populations of some soilborne plant pathogenic fungi and nematodes (14,24,42,71,72,90,92,97–99). Soil solarization is most successful in loamy to clay soils within arid or semiarid regions with intense sunlight and minimal rainfall. In sandy soils, such as those that commonly occur within the southeastern United States and California, with poor water-holding capacity and rapid drainage, heat transfer and pest control may be inhibited in deeper soil horizons (40,71). In some cases, a loss of pest control may be directly correlated with soil depth.

Many improvements and innovative ideas in system design and management will be required to successfully implement soil solarization on a commercial agricultural basis. For example, to enhance solarization effectiveness in sandy soils, drip irrigation systems may have to be installed or even buried under the plastic mulch to maintain higher soil moisture content to increase the thermal conductivity of soil and to thermally sensitize soil microorganism. The high cost of integrating solarization into a vegetable row crop management system warrants consideration of solarizing of individual rows or plant beds (27), and painting the clear mulch covers to allow use of the mulch for crop production after the solarization period.

Because solarization alone is unlikely to substitute directly for MBr, an integrated system, with solarization in combination with other tactics, must also be considered (98). For example, the combined use of soil solarization with solar heated water (90) and (or) pesticides (97) may improve pest control and foster an increased use of solarization (18). There is some potential for combining solarization with specific organic amendments (22) or biological antagonists (23). These alternative approaches have not been intensively studied and additional research will be required to maximize pest-specific efficacy, consistency, and geographical adaptability.

The high cost of labor and landfill charges to remove and dispose of the plastic mulch also suggests that new recycling technologies or sprayable, biodegradable mulches will need to be developed and evaluated.

Chemical Control Alternatives

Nonfumigant nematicides: Most studies that have been performed to evaluate nonfumigant nematicides have not always been consistent, either for controlling intended pests or for obtaining consistent economic returns to the grower, particularly when compared with conventional preplant mulched fumigation with MBr. Given the similar modes of action of these nematicides, some of the performance inconsistencies after repeated use may be due to enhanced biodegradation (44,101). As the name implies, nematicides are specific to nematodes, thus generally requiring integrated use of other herbicides, insecticides, and (or) fungicides. Because many are reasonably mobile and readily leached, particularly in sandy, low organic soils, additional research will likely be required to minimize environmental risks (28,59) while maximizing root zone retention.

Fumigant nematicides—metham sodium: Metham sodium is a water soluble preplant soil fumigant that will likely be used by some growers in the event MBr is no longer available (55,56,105,106). Unlike MBr and other fumigants, vapor diffusion of MIT (the bioactive chemical, methylisothiocyanate, of metham sodium) is relatively slow due to its high affinity for the water phase (25,40,48,95,96). Because of these characteristics, continuous delivery in irrigation water (chemigation) following premixing has generally resulted in more uniform soil distribution with enhanced nematode control and crop yield compared with conventional chisel injection methods (9,40,55,81). Much of the vegetable production acreage in the southeastern United States will require adoption of drip or trickle irrigation technology in order to use metham sodium effectively. In some areas overhead, center pivot irrigation systems are being used for metham sodium delivery. The often poor lateral dispersion of metham sodium in the sandy soils of much of the southeast and some California areas need to be addressed through improved application systems and (or) planting practices such as narrower bed widths, multiple drip tubes per bed, closer emitter spacing, and (or) planting practices that place plants closer to the drip tubes (9,55, 56).

1,3–dichloropropene: The fumigant, 1,3–dichloropropene (1,3-D) has a narrow spectrum of toxicological activity (38,48, 73). It provides excellent control of nematodes and some soilborne insects. However, it has limited activity against other soilborne pathogens or weeds and is often used in combination with chloropicrin to increase its spectrum of activity (38,48,73). Currently, 1,3-D is not registered for use in California. During the past decade it was withdrawn for sale in south Florida because of possible environmental problems, however, this policy has been recinded recently. It is likely its use will be limited in south Florida to fields that do not have a shallow water table.

Further Constraints to Implementation

Grower concerns: It is our opinion that growers would prefer to spread their risks in an integrated pest management (IPM) approach by employing a number of different tactics (many of those listed above) to reduce nematode population densities to subeconomic levels rather than relying exclusively on a single approach such as MBr. Unfortunately, many of the alternative tactics discussed have major constraints or incompatibilities which have prevented them from being widely adopted (40,51,73,85), such as high costs, lower efficacy, increased production risks, and (or) inconsistent returns to investment.

Growers are also concerned that many of the currently available alternatives will result in the loss of opportunity to plant certain crops, or to plant them on an annual basis in the same market windows, or that higher post–harvest nematode population densities will preclude opportunities for cost recovery through multiple cropping. There is also some concern that harvesting schedules may be protracted due to nonuniform maturation of the crop caused by increased pest pressures. This would increase harvesting costs, and reduce farm gate crop values due to increased competition with other national and international producers and lower prices. In fact, the real fear among many growers is that international producers will effectively capture the bulk of the U.S. market because they are not obligated by U.S. laws and standards.

From an economic perspective, a grower's primary objective is to determine which blend and sequence of different crops or production practices will yield the maximum net revenue given their own production constraints, including land, labor, capital, pest, and market conditions.

Economic analysis must reflect variations in edaphic and environmental conditions, as well as the pest complex present. To address these constraints, there is a distinct need to initiate whole farm research programs (93) and economic analyses that consider and evaluate combinations of chemical and nonchemical crop and pest management practices. This research is needed to provide future guidance for grower transition from dependence on MBr for soil pest control.

Cropping models and the nematode-crop management decisions derived from them are based on knowledge of the reduction in yield potential of the crop (2,18, 19,63,102). Management decisions are based on economic considerations that relate control costs and reductions in crop yield to profits (20,52). The need to anticipate damage in planning management strategies is justification for study of nematode damage functions and economic thresholds and their associated variability. The planning process must show how the action adopted in one season can affect the level of pest attack in the following season. The decision analysis should, therefore, be conducted in a multiyear framework to illustrate how dividends and costs from current practices are conferred in future years (93).

Nematode sampling strategies, damage functions, and economic thresholds are not quantitatively defined for most crops, cultivars, and environments. In some analyses, nematode population prediction was the limiting component for the use of a particular strategy (63). In other cases, preplant assessments of nematode densities may not even be considered because of the availability and routine use of broad-spectrum fumigant eradicants (53). There is a need for research to improve field sampling methodologies and to expedite the development and implementation of molecular diagnostic tests that can discriminate species within field populations of plant pathogens (13,29). These new diagnostic tools are needed to develop more prescriptive IPM recommendations.

Informational constraints: In addition to grower constraints there are also significant information voids that prevent information delivery by the cooperative extension service. These information constraints include the following: 1) the inability to accurately assess nematode population levels and to predict crop loss, particularly with regard to interactions with other soilborne pathogens; 2) the availability of profitable, cost-effective preplant alternative tactics; and 3) supporting data for preplant and postplant recommendations for pest management. It should be stated that at least with respect to nematodes, successful management begins with reducing their population densities in the field before planting. Given available technology, there is no consistently effective way to rescue a crop once it is infected by nematodes.

Information that has been developed elsewhere can be useful, but in most cases new studies relating efficacy, environmental impacts, suitability, and economic consequences, must be independently developed by region. Consequently, it will be necessary to evaluate different crop management strategies with respect to geographic, host plant, varietal, and soil conditions. For example, soil texture and geographic location are likely to directly influence the successful implementation of some nonchemical tactics to nematode control, such as the use of soil amendments (10). In the sandy, highly permeable, organically poor soils of Florida, the challenge for more sustainable approaches to nematode control may be in developing ways to maintain or enhance soil organic matter. Further research towards a more complete understanding of the ecology of crop production systems should serve as a foundation for nematode management.

Future Outlook

To growers: In the past, when other conventional nematicides or soil fumigants have been withdrawn from the market, replacement chemicals or nonchemical strategies were available or soon developed. With the loss of MBr, there will be no single replacement that will provide similar efficacy for all pest and disease problems. With the lower efficacy and pest specificity of many alternatives, growers will be forced to adopt IPM principles and practices.

Growers who fail to conduct periodic pest inventories and modify cropping practices accordingly will undoubtedly suffer the most; they will likely be forced by economics to discontinue production. For most growers, pest monitoring and damage assessments will become an integral component of their IPM program. In some cases, as for root-knot nematodes, simple crop monitoring systems are currently under development (57). At the very least, and as Wallace (109) so aptly pointed out, growers will be forced to live with, and accept, some disease within the field.

The real key to the economic stability of some cropping systems, e.g., tomato in Florida, will likely be contingent upon impacts of alternative strategies on marginal costs and returns to production, particularly when one considers the removal of international trade barriers and increased market competition (108). For example, as the provisions of the North American Free Trade Agreement are implemented over time, marketing costs for Mexican tomato imports will be reduced significantly, allowing direct shipment to northern markets. This factor, coupled with increased U.S. production costs associated with the removal of MBr and with other regulatory measures, may result in a significant loss of market share in the United States. This is likely to happen to Florida tomato producers irrespective of whatever replaces MBr. The result may be a redistribution of production acreage or a shift in land use patterns, including crop or farming system diversification, entirely new crops, or housing developments.

In the final analysis, the extent to which industries are affected will be determined mostly by the innovativeness and resourcefulness of growers. We hope that growers' search for alternative pest control strategies will occur in a cooperative spirit, supported by new state, federal, and commodity–sponsored research.

To nematologists: Multidisciplinary research will be needed to study the affects of MBr withdrawal, including the efficacy of alternatives for management of the complex of soilborne pests and pathogens that currently limit crop production (as well as new ones that appear later). In the past, there was no need to develop such systems, particularly those based on epidemiological concepts. Of those systems currently under study, none are yet suitably developed for immediate transfer and adoption by growers, at least not without inherent risks.

As indicated in previous sections of this document, many tactics require immediate research. No single method will provide equivalent control, and the present challenge to nematologists is the development of integrated, sustainable tactics in which different combinations of methods are used to manage nematodes. Because MBr alone meets preplant pest management needs, alternative strategies will most likely involve the combined use of pest resistant or tolerant cultivars, cultural practices, biotic agents or natural products, and other pest specific pesticides.

Short–term approaches will probably focus on currently registered replacement chemicals in combination with other practices. Within the context of new chemical research, it would be prudent to attempt to reduce the problems associated with MBr use, particularly if economic impact assessments are accurate and suitable alternatives cannot be developed and implemented by 2001. The development of these alternative pest control practices may have to occur during a period of student shortage in nematology, a diminishing number of applied research nematologists, and a critical shortage of funds to conduct the research necessary to solve the potential problems created by the removal of MBr (4).

To extension: The Cooperative Extension Service (CES) will be similarly challenged with respect to information and technology transfer. To organize, structure, or simply to archive new IPM information for rapid retrieval or dissemination will require the development of computerized databases and decision support software. The development of the databases and software should include state, regional, and national levels of organization. New educational programs and special training seminars for county extension agents, farm advisors, agricultural consultants, and farm employed pest managers will also have to be conducted at numerous locations to ensure and expedite information transfer. New procedures for plant disease diagnosis, soil analysis, and pest identification and quantification will also have to be demonstrated to ensure adoption.

To achieve these goals, adequate funds, equipment, and personnel to support information and technology transfer activities (e.g., computers, publication costs, travel) must be made available. Development of regional demonstration projects, farms, and diagnostic centers will also be required to provide site locations for cropping, efficacy, and geographical adaptability testing and grower review. To achieve these goals will require a concerted effort among research and extension personnel, as well as growers, to develop effective and economically acceptible strategies for nematode control.

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