Chapter 4.
Nematodes and Their Management

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Plant parasitic nematodes are microscopic roundworms which live in the soil and attack the roots of plants. Crop production problems induced by nematodes therefore generally occur as a result of root dysfunction, reducing rooting volume and foraging and utilization efficiency of water and nutrients. Many different genera and species of nematodes can be important to crop production in Florida. In many cases a mixed community of plant parasitic nematodes is present in a field, rather than having a single species occurring alone. In general, the most widespread and economically important nematode species include the root-knot nematode, Meloidogyne spp., and sting nematode, Belonolaimus longicaudatus. The host range of these nematodes, as with others, include most if not all of the commercially grown vegetables within the state (Table 1). Yield reductions can be extensive but vary significantly between plant and nematode species. In addition to the direct crop damage caused by nematodes, many of these species predispose plants to infection by fungal or bacterial pathogens or transmit virus diseases, which contributes to additional yield reductions.

BIOLOGY & LIFE HISTORY

Most species of plant parasitic nematodes have a relatively simple life cycle consisting of the egg, four larval stages and the adult male and female. Development of the first stage larvae occurs within the egg where the first molt occurs. Second stage larvae hatch from eggs to find and infect plant roots or in some cases foliar tissues. Host finding or movement in soil occurs within surface films of water surrounding soil particles and root surfaces. Depending on species, feeding will occur along the root surface or in other species like root-knot, young larval stages will invade root tissue, establishing permanent feeding sites within the root. Second stage larvae will then molt three times, to become adult male or female. For most species of nematodes, as many as 50 to 100 eggs are produced per female, while in others such as root-knot, upwards of 2,000 may be produced. Under suitable environmental conditions, the eggs hatch and new larvae emerge to complete the life cycle within 4 to 8 weeks depending on temperature. Nematode development is generally most rapid within an optimal soil temperature range of 70 to 80°F.

Table 1. Plant parasitic nematodes known to be of economic importance to vegetable crops in Florida.

Nematode	Bean and Pea	Carrot	Celery	Crucifers	Cucurbits	Leaf Crops	Okra	Onion	Potato	Sweet Corn	Sweet Potato	Tomato	Pepper	Eggplant
Root Knot	x	x	x	x	x	x	x	x	x		x	x	x	x
Sting	x	x	x	x	x	x	x	x	x	x		x	x	x
Stubby Root	x		x	x		x		x	x	x		x	x	x
Root Lesion										x				
Cyst				x										
Awl	x		x											
Stunt										x				
Lance										x				
Spiral										x				
Ring														
Dagger														
Bud and Leaf														
Reniform	x										x			

SYMPTOMS

Typical symptoms of nematode injury can involve both aboveground and belowground plant parts. Foliar symptoms of nematode infestation of roots generally involve stunting and general unthriftiness, premature wilting and slow recovery to improved soil moisture conditions, leaf chlorosis (yellowing) and other symptoms characteristic of nutrient deficiency. An increased rate of ethylene production, thought to be largely responsible for symptom expression in tomato, has been shown to be closely associated with root-knot nematode root infection and gall formation. Plants exhibiting stunted or decline symptoms usually occur in patches of variable growth rather than as a overall decline of plants within an entire field.

The time in which symptoms of plant injury occur is related to nematode population density, crop susceptibility, and prevailing environmental conditions. For example, under heavy nematode infestation, crop seedlings or transplants may fail to develop, maintaining a stunted condition, or die, causing poor or patchy stand development. Under less severe infestation levels, symptom expression may be delayed until later in the crop season after a number of nematode reproductive cycles have been completed on the crop. In this case aboveground symptoms will not always be readily apparent early within crop development, but with time and reduction in root system size and function, symptoms become more pronounced and diagnostic.

Root symptoms induced by sting or root-knot nematodes can oftentimes be as specific as above ground symptoms. Sting nematode can be very injurious, causing infected plants to form a tight mat of short roots, assuming a swollen appearance. New root initials generally are killed by heavy infestations of the sting nematode, a symptom reminiscent of fertilizer salt burn. Root symptoms induced by root-knot cause swollen areas (galls) on the roots of infected plants. Gall size may range from a few spherical swellings to extensive areas of elongated, convoluted, tumorous swellings which result from exposure to multiple and repeated infections. Symptoms of root galling can in most cases provide positive diagnostic confirmation of nematode presence, infection severity, and potential for crop damage.

DAMAGE

For most crop and nematode combinations the damage caused by nematodes has not been accurately determined. Most vegetable crops produced in Florida are susceptible to nematode injury, particularly by root-knot and sting nematodes (Table 1). Plant symptoms and yield reductions are often directly related to preplant infestation levels in soil and to other environmental stresses imposed upon the plant during crop growth. As infestation levels increase so then does the amount of damage and yield loss. In general, the mere presence of root-knot or sting nematodes suggests a potentially serious problem, particularly on sandy ground during the fall when soil temperatures favor high levels of nematode activity. At very high levels, typical of those which might occur under double cropping, plants may be killed. Older transplants, unlike direct seed, may tolerate higher initial population levels without incurring a significant yield loss.

FIELD DIAGNOSIS & SAMPLING

Because of their microscopic size and irregular field distribution, soil and root tissue samples are usually required to determine whether nematodes are causing poor crop growth or to determine the need for nematode management. For nematodes, sampling and management is a preplant or postharvest consideration because if a problem develops in a newly planted crop there are currently no postplant corrective measures available to rectify the problem completely once established. Nematode density and distribution within a field must therefore be accurately determined before planting, to guarantee that a representative sample is collected from the field. Nematode species identification is currently only of practical value when rotation schemes or resistant varieties are available for nematode management. This information must then be coupled with some estimate of the expected damage to formulate an appropriate nematode control strategy.

Advisory or Predictive Sample: Samples taken to predict the risk of nematode injury to a newly planted crop must be taken well in advance of planting to allow for sample analysis and treatment periods if so required. For best results, sample for nematodes at the end of the growing season, before crop destruction, when nematodes are most numerous and easiest to detect. Collect soil and root samples from 10 to 20 field locations using a cylindrical sampling tube, or if unavailable, a trowel or shovel. Since most species of nematodes are concentrated in the crop rooting zone, samples should be collected to a soil depth of 6 to 10 inches. Sample in a regular pattern over the area, emphasizing removal of samples across rows rather than along rows. One sample should represent no more than 10 acres for relatively low-value crops and no more than 5 acres for high-value crops. Fields which have different crops (or varieties) during the past season or which have obvious differences either in soil type or previous history of cropping problems should be sampled separately. Sample only when soil moisture is appropriate for working the field, avoiding extremely dry or wet soil conditions.

Diagnostics on Established Plants: Roots and soil cores should be removed to a depth of 6 to 10 inches from 10 to 20 suspect plants. Avoid dead or dying plants, since dead or decomposing roots will often harbor few nematodes. For seedlings or young transplants, excavation of individual plants maybe required to insure sufficient quantities of infested roots and soil. Submission of additional samples from adjacent areas of good growth should also be considered for comparative purposes.

For either type of sample, once all soil cores or samples are collected, the entire sample should then be mixed thoroughly but carefully, and a 1 to 2 pint subsample removed to an appropriately labeled plastic bag. Remember to include sufficient feeder roots. The plastic bag will prevent drying of the sample and guarantee an intact sample upon arrival at the laboratory. Never subject the sample(s) to overheating, freezing, drying, or to prolonged periods of direct sunlight. Samples should always be submitted immediately to a commercial laboratory or to the University of Florida Nematode Assay Laboratory for analysis. If sample submission is delayed, then temporary refrigeration is recommended at temperatures of 40 to 60°F.

Recognizing that the root-knot nematode causes the formation of large swollen areas or galls on the root systems of susceptible crops, relative population levels and field distribution of this nematode can be largely determined by simple examination of the crop root system for root gall severity. Root gall severity is a simple measure of the proportion of the root system which is galled. Immediately after final harvest, a sufficient number of plants should be carefully removed from soil and examined to characterize the nature and extent of the problem within the field. In general, soil population levels increase with root gall severity. This form of sampling can in many cases provide immediate confirmation of a nematode problem and allows mapping of current field infestation. As inferred previously, the detection of any level of root galling usually suggests a nematode problem for planting a susceptible crop, particularly within the immediate areas from which the galled plant(s) were recovered.

GENERAL MANAGEMENT CONSIDERATIONS

Currently nematode management considerations include crop rotation of less susceptible crops or resistant varieties, cultural and tillage practices, use of transplants, and preplant nematicide treatments. Where practical, these practices are generally integrated into the summer or winter ‘off-season’ cropping sequence. It should be recognized that not all land management and cultural control practices are equally effective in controlling plant parasitic nematodes and varying degrees of nematode control should be expected. These methods, unlike other chemical methods, tend to reduce nematode populations gradually over time. Farm specific conditions, such as soil type, temperature, and moisture, can be very important in determining whether different cultural practices can be effectively utilized for nematode management.

CULTURAL PRACTICES

Crop Rotation

For crop rotation to be effective, crops unsuitable for nematode infection, growth, or reproduction must be introduced into the rotation sequence. In most of Florida it is not uncommon to observe a multispecies community of nematodes all occurring within the same field. Under these circumstances it may not be possible to find a rotation or cover crop that will effectively reduce populations of all nematode pests, particularly if root-knot and sting nematodes occur in combination In this case, crop rotations detrimental to root-knot, which is generally the most difficult to control, should be selected. In some cases, resistant crop varieties are available which can be used within the rotation sequence to minimize problems to some species of root-knot but not sting nematodes.

Use of poor or nonhost cover crops within the rotation sequence, may in some cases offer an effective approach to nematode control. Two leguminous cover crops adaptable for managing soil populations of sting or root-knot nematode include hairy indigo (*Indigofena hirsuta*) and American jointvetch (*Aeschynomene americana*). Sorghum is also a popular cover crop restoring large amounts of soil organic matter, but is a good host for sting nematode but not root-knot. Most of the small grains commonly used as winter cover crops in central and north Florida, such as rye, barley, wheat or oats, can support limited reproduction of root-knot nematode. To avoid an increase in root-knot populations, these crops should only be planted when soil temperatures are below 65°F, a threshold temperature for nematode activity.

Cover crop rotations with some pastureland grasses (particularly pangola digitgrass, and to some extent Bahiagrass, and bermuda grass) have significantly reduced, but not eliminated, root-knot nematodes. In north Florida, long term (6- to -9 year) pastureland rotations have allowed economic watermelon production within root-knot infested fields. It should be recognized that as the crop rotation period is shortened or eliminated, nematode problems will intensify accordingly. Other perennial legumes currently under evaluation may play an important role in future nematode management programs.

For cover crops to be most effective, stands must be established quickly and undesirable weeds which can serve as alternative hosts must be controlled. Given that many different weeds serve as alternative plant hosts to nematodes (i.e. nutsedges), it may not be possible to manage root-knot nematode with crop rotation unless an integrated program to manage weeds is also considered and implemented within the field. With many cover crops, rapid stand establishment has been a significant problem. Similarly, economic crop rotation sequences are often further complicated by lack of crop management skills, specialized equipment to grow and harvest the crop, or by the lack of closely located processing facilities or markets. In some cases other measures should be considered such as fallowing which is usually as efficient as crop rotation for reducing field infestations of nematodes.

Fallowing

Clean fallow during the off-season is probably the single most important and effective cultural control measure available for nematodes. When food sources are no longer readily available, soil population densities of nematodes gradually decline with death occurring as a result of starvation. Due to the wide host range of many nematode species, weeds and crop volunteers must be controlled during the fallow period to prevent nematode reproduction and further population increase. At least two discing operations are generally required to maintain clean fallow soil conditions during the interim period between crops. Fallowing by use of herbicides to deplete nematode populations is a much slower process because the soil is not disturbed, thereby subjecting nematodes from deeper soil layers to the drying action of sun and wind. The unfavorable effects of fallowing on soil organic matter and soil structure are usually more than compensated for by the level of nematode control achieved and the resulting increase in crop productivity. When soil erosion is a potentially serious problem other measures should be considered.

Biological Control

At present there are no effective, commercially available, biological control agents which can be successfully used to control nematodes.

Biorational Compounds

The active ingredients of these compounds can best be described as either microbial agents or derived toxins, plant extracts or dried plant products, or simple blends of fatty acids, stabilized colloids, or secondary alcohols. In general, suitable and/or consistent nematode control and crop yield enhancement has not been achieved with these products. Further research characterizing the utility of these compounds under different environmental conditions, and the ways and means in which to increase their effectiveness is necessary.

Plant Resistance

Use of nematode-resistant crop varieties has not been extensively evaluated in Florida, but is often viewed as the foundation of a successful integrated nematode management program on all high value crops in which methyl bromide is currently used. Commercially available nematode-resistant varieties are currently available only for tomato, pepper, southernpea, and sweetpotato. In a resistant variety, nematodes fail to develop and reproduce normally within root tissues, allowing plants to grow and produce fruit even though nematode infection of roots occurs. Some crop yield loss can still occur however, even though the plants are damaged less and are usually significantly more tolerant of root-knot infection than that of a susceptible variety.

In tomato, a single dominant gene (subsequently referred to as the Mi gene) has been widely used in plant breeding efforts and varietal development which confers resistance to all of the economically importance species of root-knot nematode found in Florida, including *Meloidogyne incognita, M. arenaria,* and *M. javanica*. Commercially resistant fresh market varieties, climatically and horticulturally adapted for Florida are available as an effective nematode management tactic in tomato. Unfortunately, in previous research with resistant tomato varieties, the resistance can fail as a result of the heat instability or apparent temperature sensitivity of the resistant Mi gene. For example, previous research has demonstrated threshold soil temperatures and incremental reductions in nematode resistance with each degree above 78°F, such that at 91°F tomato plants are fully susceptible. This would suggest that in Florida, use of these varieties may be better suited for spring plantings when cooler soil temperatures prevail.

In pepper, two root-knot nematode resistant varieties (‘Carolina Belle’ and ‘Carolina Wonder’) were released from the USDA Vegetable Research Laboratory for commercial seed increase in April 1997. Both varieties are open pollinated, and homozygous for the N root-knot nematode resistant gene. Preliminary research has demonstrated that these varieties confer a high degree of resistance to the root-knot nematode, however expression of resistance is heat sensitive. Further research is necessary to characterize the usefulness of these varieties under the high soil temperature conditions of Florida. Further research to incorporate the resistance genes into other commercial available lines and varieties is also required. Like tomato, use of these varieties may have to be restricted to spring plantings when cooler soil temperatures prevail.

In addition, to problems of heat instability, the continuous or repeated planting of resistant plant varieties will almost certainly select for virulent races of *Meloidogyne* capable of overcoming the resistance. Therefore the duration and/or utility of the resistance may be time-limited. In previous studies with resistant tomatoes, resistance breaking nematode races develop within 1 to 3 years. Since new races of the nematode can develop so rapidly, a system of integrated control usually mandates the rotation of resistant and non-resistant varieties to slow the selection process for new virulent races. Recent trials in Florida have already demonstrated the capacity of some species or races of root-knot to reproduce and inflict damage upon a resistant tomato variety. The results of this research have demonstrated that even with a resistant variety, which was damaged less than a susceptible variety, some consideration of initial soil population levels of the root-knot nematode must be observed to minimize tomato yield losses. Given that significant yield losses can still occur, combined efforts to manage soil populations to low levels prior to planting must still be considered, particularly if tomatoes are planted as a fall crop. If this situation develops, the combination of a nematicide and resistant variety may also comprise an option to reduce nematode populations to acceptable levels.

Soil Amendments

Many different types of amendments and composted materials have been applied to soil to suppress populations of plant parasitic nematode and improve crop yield and plant health. Animal manures, poultry litter, and disk-incorporated cover crop residues are typical examples of soil amendments used in agriculture to improve soil quality and as a means for enhancing biocontrol potential of soil. Some amendments which contain chitin and inorganic fertilizers that release ammoniacal nitrogen into soil suppress nematode populations directly and enhance the selective growth of microbial antagonists of nematodes. More recently, composted municipal wastes and sludges have been used to amend soil to improve soil fertility, organic matter content, water holding capacity, nutrient retention, and cation exchange capacity.

Suppression of soilborne pathogens via the incorporation or simple mulching of composted amendments is reputedly based on enhanced microbial activity and increased numbers of antagonists generated by decomposition of the amendment in soil. Soils with a diversity of beneficial microorganisms are more suppressive to pathogens than soils with little or no biological diversity. Other possible mechanisms for pathogen suppression by composts include direct inhibition of the pathogen or reduced infectivity of the organisms into the plant host. Population increases of beneficial organisms in soil appears to be the direct result of environmental changes brought about by the amendments after addition to soil. This suggests that to sustain soil suppressiveness, amendments must be periodically reapplied to maintain the soil environment conducive to antagonists.

The level to which soilborne pest and disease control can be achieved is not only related to the type of material but to the age of the compost. Nematode and disease suppression has been repeatedly demonstrated with composted municipal yard wastes containing significant quantities of tree bark. If the compost is immature, the product may not only be difficult to handle and have an offensive odor, but may contain salts and metabolites toxic to plants. For example, weed suppression has been demonstrated with some types of immature composted materials which contain and or produce organic acids with phytotoxic properties. Other studies have shown that soils amended with different sources of composted municipal wastes were disease suppressive as long as they were relatively fresh (< 6 months), but as the composted municipal waste was aged, disease suppressiveness was lost. In other Florida studies, application of composted municipal wastes at rates up to 120 tons per acre have not been shown to have pesticidal activity, but actually dramatically increased populations of nematodes and other disease organisms such as Fusarium and *Phytopthora spp*. Nematode population increases were directly related to increases in plant growth and root system size with amendment application rate.

Recent studies in Florida have been conducted to determine the extent to which increasing application rates of a municipal solid composted waste affect the ability of tomato plants to tolerate root infection by species of root-knot nematode (*Meloidogyne spp*.) These studies showed that in a sandy soil, poor in organic matter content (less than 2%), tomato yields could be increased significantly with soil amendments in both nematode free or nematode infested soil. The impact of the root-knot nematode on tomato yield was effectively constant however, suggesting that application of the soil amendment did not enhance the ability of tomato plants to tolerate infection by the root-knot nematode. Much of the previous and ongoing research in Florida also seems to indicate that the major effects of soil amendments to crop yields appear to be less related to nematode or soil pathogen control than to enhanced plant nutrition and nutrient and water availability.

It is not clear at this time and preliminary stage of university field research whether benefits to crop growth after the initial crop following soil amendment application can be expected. Recent studies showed no response in second crop tomato yields (double crop) following amendment application rates from 15 to 120 tons per acre. Disappearance of nutrients and soil organic matter content appears to be very rapid in the hot, moist soils of Florida. Reapplication of the amendments may have to be made on at least an annual basis to sustain crop growth and yield benefits. In summary, the high rates of application (tons/acre) and attendant costs required for crop response and nematode control for many different types of organic amendments, and the apparently rapid losses of the materials in soil appears to restrict use of these materials primarily to homeowner or small farm operations at this time. However, with additional research and advances in application technology and use efficiency, use of soil amendments may become an integral component of Florida crop production systems.

Flooding

Extended periods of flooding suppresses nematode populations. Alternating 2 to 3 week cycles of flooding and drying are more effective than long, continuous flooding cycles. At present, only limited areas within the state are situated to take advantage of flooding as a viable means of nematode control. Given the growing concern about aquifer depletion, salt water intrusion, and water use inefficiencies, it seems unlikely that Florida water management officials will continue to permit flooding within these areas in the future.

Soil Solarization

Soil solarization is a nonchemical technique in which transparent polyethylene film is laid over moist raised beds for a 6 to 12 week period to heat noncropped soils to temperatures lethal to nematodes and other soil-borne pathogens. Soil temperatures are magnified due to the trapping of incoming solar radiation under the clear, polyethylene panels. To be effective, soils must be wetted and maintained at high soil moisture content to increase the susceptibility (thermal sensitivity) of soil borne pests and thermal conductivity of soil. Wet mulched soils increase soil temperatures due primarily to the elimination of heat loss by evaporation and upward heat convection, in addition to a greenhouse effect by prohibiting dissipation of radiation from the soil. At the end of the solarization period the clear plastic is painted with a white or black latex paint to allow continued use of the plastic as a mulch cover for the production of vegetables on raised beds.

The most successful use of soil solarization appears to occur in heavier (loamy to clay soils) rather than sandy soils. Soils with poor water holding capacity and rapid drainage can significantly inhibit heat transfer to deeper soil horizons. Loss of pest control is directly correlated with soil depth. The depth to which lethal temperature can be achieved (6 to 8 inches) is also dependent on the intensity and duration of sunlight and ambient temperature. At present, the only time to consider soil solarization for pest control is during our hot, summer and early fall months, which fortunately are 'off-season' in most peninsular Florida vegetable row crops. Unfortunately, our summers are also our wettest period of the year with frequent afternoon rain showers which have a cooling effect on the soil.

Many different pests have been suppressed and or controlled by soil solarization, particularly within arid environments with intense sunshine, and limited cloud cover and rainfall. Soil solarization can also be effective in a subtropical environment. Plant parasitic nematodes have generally proved to be more difficult to control with soil solarization, as have some weed pests such as crabgrass and purslane in a central Florida study. The results of preliminary experiments are also suggesting the potential for selection pressures towards a buildup of heat tolerant individuals which may serve to reduce soil solarization efficacy after repeated use as a nematode control tactic.

In some studies, effective use of solarization for nematode control has required an integrated systems approach, coupling solarization with other chemical or nonchemical approaches. For example, the combined use of soil solarization with a nematicide has improved nematode control and crop yield. In addition, use of virtually impermeable, photo-selective plastic mulches may also complement low dose fumigant treatments to reduce weed germination and growth in the event of extended periods of cloud cover occurring during the solarization regime. At this time, further research is needed demonstrating soil solarization pest control activity and consistency in the various geographical regions of Florida where vegetable crops are grown.

Other Cultural Practices

Other cultural measures which reduce nematode problems include rapid destruction of the infested crop root system following harvest. Fields which are disced as soon as possible after the crop is harvested will not only prevent further nematode population growth but subject existing populations to dissipation by sun and wind. Use of nematode free transplants is also recommended since direct seeded plants are particularly susceptible since they are vulnerable to injury for a longer duration, during an early, but critical period of crop development. Since nematodes can be carried in irrigation water that has drained from an infested field, growers should avoid use of ditch or pond waters for irrigation or spray mixtures. In most cases, a combination of these management practices will substantially reduce nematode population levels, but will rarely bring them below economically damaging levels. This is especially true of lands which are continuously planted to susceptible crop varieties. In these cases some form of pesticide assistance will still usually be necessary to improve crop production.

CHEMICAL CONTROL

Nonfumigant Nematicides

All of the nonfumigant nematicides (Table 2) currently registered for use are soil applied, with the exception of Vydate, which can also be applied foliarly. They must be incorporated with soil or carried by water into soil to be effective. These compounds must be uniformly applied to soil, targeting the application toward the future rooting zone of the plant, where they will contact nematodes or, in the case of systemics, in areas where they can be readily absorbed. Placement within the top 2 to 4 inches of soil should provide a zone of protection for seed germination, transplant establishment, and protect initial growth of plant roots from seeds or transplants. Studies performed in Florida and elsewhere to evaluate non-fumigant 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 methyl bromide or other broadspectrum fumigants. As the name implies, they are specific to nematodes, requiring integrated use of other cultural or chemical pest control measures. Many are reasonably mobile and are readily leached in our sandy, low organic matter soils, thus requiring special consideration to irrigation practices and management.

Nematode management must be viewed as a preplant consideration because once root infection occurs and plant damage becomes visible it is generally not possible to resolve the problem completely so as to avoid potentially significant yield losses. Recently, experiments were conducted to evaluate the extent to which tomato plant growth and yield could be 'rescued' from root-knot nematode via early detection and treatment by post plant applications of the nonfumigant nematicide, Vydate (Oxamyl). The results of these experiments clearly showed that it was not possible to completely resolve the problem and avoid tomato yield losses with post plant applications of Vydate. This was particularly obvious in tomato yield responses with foliar applications of Vydate attempting to resolve a soil-borne problem. If an attempt is going to be made to rescue the crop, the sooner the nematode problem is recognized and soil applications of Vydate started, the greater the improvement in tomato yields relative to plants maintained nematode free.

Fumigant Nematicides

In Florida, use of broadspectrum fumigants (Table 2) effectively reduces nematode populations and increases vegetable crop yields, particularly when compared with nonfumigant nematicides. Since these products must diffuse through soil as gases to be effective, the most effective fumigations occur when the soil is well drained, in seedbed condition, and at temperatures above 60°F. Fumigant treatments are most effective in controlling root-knot nematode when residues of the previous crop are either removed or allowed to decay. When plant materials

Table 2. Non-Fumigant Nematicides Registered for Vegetable Crop Use in Florida

	Non-Fumigant Nematicides			
Vegetable	**Mocap**	**Counter**	**Temik**	**Vydate**
Beans	*			
Carrots				*
Celery				*
Corn, sweet	*	*		
Cabbage	*			
Brussels sprouts				
Cucumber	*			*
Melons				*
Squash				*
Okra				
Potatoes	*		*	*
Potatoes, sweet	*		*	*
Eggplant				*
Tomato				*
Pepper				*
Strawberry				

This information was compiled as a quick reference for the commercial Florida vegetable grower. The mentioning of a chemical or proprietary product in this publication does not constitute a written recommendation or an endorsement for its use by the University of Florida, Institute of Food and Agricultural Sciences, and does not imply its approval to the exclusion of other products or practices that may be suitable. Products mentioned in this publication are subject to changing State and Federal rules, regulations and restrictions. Additional products may become available or approved for use. Growers have the final responsibility to guarantee that each product is used in a manner consistent with its label.

have not been allowed to decay, fumigation treatments may decrease but not eliminate populations of root-knot nematodes in soil. Crop residues infested with root-knot nematode may also increase soil populations to the extent that significantly higher rates of application may be required to achieve nematode control. To avoid these problems, growers are advised to plan crop destruction and soil cultivation practices well in advance of fumigation to insure decomposition of plant materials before attempting to treat the soil.

For over 40 years, Florida producers of many high value fruit and vegetable crops have relied upon methyl bromide soil fumigation to resolve their soilborne pest and disease. In 1991, methyl bromide was detected in significant concentration within the earth's stratosphere. In subsequent studies, it was shown to catalyze the destruction of ozone, and determined to be a significant contributor to stratospheric ozone depletion, thinning, and the creation of an ozone hole over Antarctica. After being classified as a Class I ozone depleting chemical in 1993, methyl bromide was mandated by the Clean Air Act of 1990 for eventual phase-out from production and agricultural use. After more than a decade long regulatory struggle with numerous reprieves, the final phase-out date for methyl bromide production, importation, and use within the U.S. proceeded as scheduled to January 1, 2005. As a grandfather clause, it is still possible to continue to use methyl bromide supplies produced prior to January 1, 2005, but only on the four currently defined 'critical use exempted' crops of tomato, pepper, eggplant and strawberry.

For tomato, pepper, eggplant and strawberry, continued post phase-out availability is now driven by a more complex process involving the use of both remaining, pre 2005 produced commercial stocks of methyl bromide, as well as those derived from new production made available only through annual award of a Critical Use Exemption (CUE). The CUE is a rather complicated, national and international regulatory process. Simplistically described, the CUE represents a U.S.A. request for continued use of methyl bromide that is submitted to and approved by an international United Nations and Montreal Protocol authority, which substantiates the need for continuing use of methyl bromide for crops and farming enterprises in which "no technically or economically feasible alternative to methyl bromide is shown to exist". We have been fortunate in that approved CUE levels for new production of methyl bromide have been awarded for calendar years 2005 through 2009. A CUE request for continued use of methyl bromide for 2010 has also been submitted for consideration and approval. Each year the approved level of new production is reduced which at some point of reduced availability will ultimately force Florida growers to transition to alternatives strategies in the very near future. Further information regarding the methyl bromide CUE process, diminishing supply and transition strategy to alternatives can be found in a subsequent chapter of this production guide.

Ultimately, the loss of methyl bromide in the U.S.A will create a void for Florida growers in the chemical arsenal currently used for soilborne pest and disease control. This fact is made quite clear from a review of recent field research trials conducted in Florida which show that no single, equivalent replacement (chemical or nonchemical) currently exists which exactly matches the broadspectrum efficacy of methyl bromide. In preparation for the ultimate phase-out and loss of methyl bromide, university research programs within Florida have been intensified to identify and evaluate more robust strategies which minimize cropping system impacts, accounting for a diverse range of pest pressures and environmental conditions. Based on summary and comparison of methyl bromide alternative chemical trial results in Florida since 1994, Telone (1,3-Dichloropropene) plus Chloropicrin) applied either separately or coformulated as Telone C35 (1.3-D plus 35% Chloropicrin) in combination with a separately applied herbicidal compound for weed control, has been identified as the best chemical alternative replacement for methyl bromide for some vegetable row crops such as strawberry and tomato. Use of other formulations of 1,3-D with higher proportionate levels and rates of application of chloropicrin have not consistently resulted in effective nematode control when compared with Telone C35 or Telone Inline.

This has also been repeatedly demonstrated in large scale, commercial field trials around the state. In these studies, use of Telone and Chloropicrin in combination with a herbicide treatment, including mini-coulter application of metam sodium or potassium to the bed top prior to installing the plastic mulch, generally resulted in near equivalent yields to that of methyl bromide. With repeated long term use, or under conditions of high pest pressures (weeds, nematodes, disease), other IPM practices might also be required and combined to achieve adequate control and economic crop productivity. For example, prebed treatments of Telone C35 (35 gal/A) or Telone II (12 gal/A) followed by an additional in-bed application of chloropicrin (150 lb/A) followed by metam sodium application (75 gal/A) to the bed top has been required for effective weed and disease control in pepper. In combination with Telone, Telone C35 or Chloropicrin, growers are also encouraged to use only a high barrier, metalized, or virtually impermeable mulch film (VIF) with measured transmissivity to methyl bromide of less than 14 grams per square meter per hour. With use of the more impermeable mulches, fumigant rates have been reduced as much as 25 to 40% from maximum labeled application rates without loss of pest control or crop yield in a number of studies. Given the potential variability, growers should consider their own small scale field trials to determine the degree to which rates reductions of the different fumigants with high barrier mulches is possible. Due to use restrictions for all Telone products in Dade County, either metham sodium or metham potassium at 75 and 60 gallons per treated acre respectively, in combination with shank injections of chloropicrin (150 pound per treated acre) and appropriate herbicide(s) are currently defined as the best alternatives to methyl bromide.

Major changes in the federal label for Telone products has recently occurred and personnel protective equipment (PPE) and buffer zone requirements have been greatly reduced, particularly for field workers with no liquid contact potential. For example, rubber boots, gloves, coveralls, and full-face respirators are no longer mandatory PPE requirements. For in-bed Telone applications, the requirement now only requires the use of a half-face respirator and safety glasses by field workers. For other applications (e.g., prebed treatments which are applied to the flat prior to bedding), PPE requirements are further reduced and do not require a half-face respirator. It is also expected however, that EPA will soon impose new product label constraints for many if not all of the other alternative fumigants currently undergoing registration by the U.S. EPA. These new label constraints are likely to include reduction of maximum rates of fumigant application per treated acre, requirements for additional pesticide and respirator training, fit testing, medical certification to ensure field workers abilities to wear respirators, and expanded buffer zones between agriculturally treated lands and urban areas. In all cases, the grower has the final responsibility to insure that the label is consulted and that each product is used legally according to the label.

As with any new technology, prebed applications of Telone or Telone C35 by growers will require some new field equipment and changes in application procedure and timing. Deep placement of Telone C-35 is not only a requirement of the pesticide label but is essential for prolonged fumigant retention in soil. Unfortunately, deep injection of prebed applications of Telone C-35 to a depth of 10 to 12 inches can be difficult to achieve because of the presence of a compacted traffic layer in most fields. To enhance treatment efficacy, growers should consider tillage operations which destroy the traffic pan to ensure fumigant diffusion within the bed and soil profile with deep placement of Telone. Federal and state regulations currently limit the application of any Telone containing product within 100 feet of any occupied structure, dwelling, or drinking water well. Unavoidably, some uncontrollable environmental factors such as temperature and rainfall can affect the performance of fumigant treatment and plant-back scheduling. Growers must therefore plan accordingly to account for any unforeseen delays in fumigant dissipation from soil and to avoid potential phytotoxic impact to crops.

All of the fumigants are phytotoxic to plants and as a precautionary measure should be applied at least 3 weeks before crops are planted. When applications are made in the spring during periods of low soil temperature, these products can remain in the soil for an extended period, thus delaying planting or possibly causing phytotoxicity to a newly planted crop. Field observations also suggest rainfall or irrigation which saturates the soil after treatment tends to retain phytotoxic residues for longer periods, particularly in deeper soil layers.

SUMMARY

In summary, nematode control measures can be conveniently divided into two major categories: cultural and chemical. None of these measures should be relied upon exclusively for nematode management. Rather, when practical and economics permit, each management procedure should be considered for use in conjunction with all other available measures for nematode control and used in an integrated program of nematode management.

In addition, to nematodes, many other pests can cause crop damage and yield losses which further enforces the development of an overall, Integrated Pest Management (IPM) program, utilizing all available chemical and nonchemical means of reducing pest populations to sub-economic levels. An IPM approach further requires that growers attempt to monitor or scout fields for pest densities at critical periods of crop growth.

Table 3. Broadspectrum Fumigant Nematicides Registered for Vegetable Crop Use in Florida

	Formulation Methyl Bromide[3] To Chloropicrin[2]		OTHER FUMIGANTS					
Crop/Use	50 50	0 100	Methyl[2] Iodide	Metam[2] Sodium	Metam[2] Potassium	Telone[1] II	Telone[1] C17	Telone[1] C35
Asparagus				*	*	*	*	*
Broccoli				*	*	*	*	*
Cauliflower				*	*	*	*	*
Cucumber		*		*	*	*	*	*
Eggplant	*	*		*	*	*	*	*
Muskmelon				*	*	*	*	*
Onions (bulb)				*	*	*	*	*
Onions		*		*	*	*	*	*
Peppers	*		*	*	*	*	*	*
Tomato	*	*	*	*	*	*	*	*
Sweet potato		*		*	*	*	*	*
Vegetable				*	*	*	*	*
Strawberry	*	*	*	*	*	*	*	*
Plant Bed		*		*	*	*	*	*
Seed Bed		*		*	*	*	*	*

[1] Crop recommendations for Telone II, Telone C17, or Telone C35 do not apply to the Homestead, Dade County production region of south Florida where soil types and water tables currently prohibit product use. Other supplementary labeling with additional county or soil and use restrictions may apply.

[2] Currently under EPA Fumigant Reregistration review, with potential label changes anticipated in 2009 to maximum application rate, high barrier impermeable mulch films, personal protective equipment, Buffer Zone, and other new restrictions and requirements.

[3] A critical use exemption (CUE) for continuing use of methyl bromide for tomato, pepper, eggplant and strawberry has been awarded for calendar year 2009. Specific certified uses and labeling requirements for existing stocks and CUE acquired methyl bromide must be satisfied prior to grower purchase and use in these crops. Formulation availability is subject to change.

This information was compiled as a quick reference for the commercial Florida vegetable grower. The mentioning of a chemical or proprietary product in this publication does not constitute a written recommendation or an endorsement for its use by the University of Florida, Institute of Food and Agricultural Sciences, and does not imply its approval to the exclusion of other products or practices that may be suitable. Products mentioned in this publication are subject to changing State and Federal rules, regulations and restrictions. Additional products may become available or approved for use. Growers have the final responsibility to guarantee that each product is used in a manner consistent with its label.