Nematode Management in Tomatoes, Peppers and Eggplant

J. W. Noling

Plant parasitic nematodes, are small 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, includes most if not all of the commercially grown vegetables within the state.

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 have also been shown to predispose plants to infection by fungal (Figure 1) or bacterial pathogens or to transmit virus diseases, which contribute 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 3 times, to become adult male or female. For most species of nematodes, as many as 50-100 eggs are produced per female, while in others such as root-knot, upwards of 2000 may be produced (Figure 2). 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.

Symptoms

Typical symptoms of nematode injury can involve both aboveground and below ground plant parts. Foliar symptoms of nematode infestation of roots generally involve stunting and general unthriftiness, premature wilting (Figure 3) and slow recovery to improved soil moisture conditions, leaf chlorosis (yellowing) (Figure 4) 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 nonuniform growth rather than as an overall decline of plants within an entire field (Figure 5).

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 (Figure 6). 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
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Figure 5. Plant stunting caused by sting (*Belonolaimus longicaudatus*) or root-knot nematode (*Meloidogyne* spp.) in various field crops. Note irregular or patchy field distribution of stunted plants rather than throughout the entire field.

apparent early within crop development, but with time and reduction in root system size and function, symptoms become more pronounced and diagnostic.

Figure 6. Root-knot nematode (*Meloidogyne* sp.) induced stunting and seedling mortality of pepper.

Root symptoms induced by sting or root-knot nematodes can oftentimes be as specific as aboveground symptoms. Sting nematode can be very injurious, causing infected plants to form a tight mat of short roots, oftentimes 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 (Figure 7). 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.

Figure 7. Close-up view of root-knot nematode (*Meloidogyne* spp.) induced galling of plant roots. Note the enlarged, tumorous type expansions (galls) of the roots.

**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, particular by root and sting nematodes. 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 (Figure 8). As infestation levels increase so then do 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 doubling cropping, plants may be killed. Older transplants, unlike direct seed, may tolerate higher initial population levels without incurring as significant a 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
Figure 8. Typical nematode induced crop damage relationship in which crop yields, expressed as a percentage of yields that would be obtained in the absence of nematodes, decline with increased population density of nematodes in soil. The tolerance level is identified as the initial or minimal soil population density at which crop damage is first observed.

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 the nematode becomes established. Nematode density and distribution within a field must therefore be accurately determined before planting, guaranteeing 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 (Prior to Planting)

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 (Figure 9). 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 (Figure 10). 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.

Figure 9. The collection of soil samples for nematode analysis can be acquired from the field using either cylindrical sampling tubes, trowels, bucket auger, or shovel.

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 may be 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 (Figure 11).

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, temporary refrigerated storage at temperatures of 40 to 60°F is recommended.

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 (Figure 12). 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 (Figure 13). 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 subsequent planting of 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 through time. Farm specific conditions, such as soil type, temperature, 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 which 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 melon 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 (ie. 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 (Figure 14). 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 is 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.

**Figure 14.** Use of field tillage operations to maintain a fallow condition within an agricultural field.

**Biological Control**

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

**Plant Resistance**

Use of nematode-resistant crop varieties have 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, southern pea, and sweet potato. 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 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*, *arenaria*, and *javanica*. Commercially resistant fresh market varieties, climatically and horticulturally adapted for Florida, have only become recently available in the tomato variety 'Sanibel'. Unfortunately, in previous research with resistance tomato varieties, the resistance has often failed as a result of the heat instability or apparent temperature sensitivity of the resistant Mi gene (Figure 15). 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 have to be restricted to spring plantings when cooler soil temperatures prevail.

In pepper, two newly developed 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. Like tomato, use of these
variety 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 have been shown to 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 these experiments have demonstrated that even with a resistant variety, which were damaged less than that of 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 nondamaging 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 be pesticidal in activity, but actually dramatically increased populations of nematodes and other disease organisms such as *Fusarium* and *Phytophthora* 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 effect 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. Preliminary research suggests that reapplication of the amendments may have to be made on 1-2 year 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 preclude 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**

Flooding has been shown to suppress nematode populations (Figure 16). Alternating 2 to 3 week cycles of flooding and drying have proven to be 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.

![Figure 16. Extended periods of off-season field flooding can promote the decline of soil population density of nematodes in production fields.](image)

**Soil Solarization**

Soil solarization is a nonchemical technique in which transparent polyethylene tarps are laid over moist soil for a 6 to 12 week period to heat noncropped soils to temperatures lethal to nematodes and other soil-borne pathogens (Figure 17). 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 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. Recent studies in Florida have demonstrated that 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 has some weed pests such as crabgrass 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 tomato 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 1) currently registered for use in tomatoes, peppers and eggplant are soil applied, with the exception of Vydate, which can also be applied foliarily. 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 and taken up into the plant. 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. Most studies which have been performed in Florida and elsewhere to evaluate nonnematicides 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 broadspectrum fumigant nematicide (Figure 18). As the name implies, they are specific to nematodes, requiring integrated use of other cultural or chemical pest control measures to manage other weed and disease pests. Many are reasonably mobile and are readily leached in our sandy, low organic soils, thus requiring special consideration to irrigation practices and management.

**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 (Figure 19), 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 have not been allowed to decay,
fumigation treatments may decrease but not eliminate populations of root-knot nematodes in soil, particularly nematodes within the egg stage. Crop residues infested with root-knot nematode may also shelter 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 fumigate.

![Figure 19. Nematode as aquatic organisms encountering both liquid and gas phase nematicides in soil.](image)

The proposed ban on methyl bromide in the U.S.A. in 2005 will no doubt create a void for us 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 shows that no single, equivalent replacement (chemical or nonchemical) currently exists which exactly matches the broadspectrum efficacy of methyl bromide. In preparation for the 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 C-17 or Telone C-35 (1,3-Dichloropropene plus 17% or 35% Chloropicrin), in combination with a separately applied herbicide for weed control, has been identified as the best chemical alternative replacement for methyl bromide for some vegetable row crops such as tomato. This has also been demonstrated in large scale, commercial field trials around the state. In these studies, use of any of the other alternative fumigants, except Telone C-17 or Telone C-35 and chloropicrin in combination with a herbicide treatment, resulted in lower yields than that of methyl bromide with increasing pest pressure. Under conditions of high pest pressures (nematodes, disease), other IPM practices might also be required and combined to achieve adequate control and economic crop productivity.

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 (Figure 20 & Figure 21). 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.

![Figure 20. Sweet corn phytotoxicity to post treatment soil residuals of metham sodium.](image)

### Summary

In summary, nematode control measures can be conveniently divided into 2 major categories including cultural and chemical control measures. 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 enforce the development of an overall, Integrated Pest Management (IPM) program, utilizing all available chemical and nonchemical means of reducing pest populations to subeconomic levels. An IPM approach further requires that growers attempt to monitor or scout fields for pest densities at critical periods of crop growth.

These crops share similar nematode problems and nematicide registrations, and are grown and handled similarly. Their most important nematode pests are root-knot (in sand, muck and Dade Co. rock-based soils), stubby-root (in sand and muck soils), and sting (in sands) nematodes. Fumigants (Table 1) are much more consistently effective against rootnematodes than the non-fumigants (Table 2); under some circumstances, non are more effective against stubby-root nematodes than are fumigants; most nematicides can be effective against sting nematodes if applied properly.

Tomatoes, peppers and, to some extent eggplant are produced on plastic-mulched beds in many areas of Florida. These beds are routinely fumigated with a multi-purpose fumigant at the time they are covered for broad spectrum soil pest control. Several brands of the fumigants used most widely for tomatoes, including many different methyl bromide/chloropicrin mixtures, have also been registered for peppers and/or eggplant. There is evidence to suggest that some formulations may be better suited for control of specific pest complexes (i.e., combinations of nematodes, weeds, and/or fungi). However, the grower must check the label of the product he is actually using to be sure that it is registered for the crops to be grown in the soil being treated. Most multi-purpose fumigants which do not contain methyl bromide may be legally used to treat production fields for nearly any vegetable crop.

For an explanation of the tables in this document, see Nematode Management in Commercial Vegetable Production.

Figure 21. Crop phytotoxicity of tomato to post treatment soil residuals of 1,3 dichloropropene.
Table 1. Non-fumigant nematicides for tomatoes, eggplants and peppers in Florida.

<table>
<thead>
<tr>
<th>Product</th>
<th>Application Rates and Procedures</th>
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<tbody>
<tr>
<td>Vydate L</td>
<td>Tomatoes, peppers and eggplants: Treat soil before or at planting with any other appropriate nematicide or a Vydate transplant water drench followed by Vydate foliar sprays or via drip irrigation system delivery at 7 to 14 day intervals through the season; do not apply within 7 days of harvest; refer to directions in appropriate &quot;state labels,&quot; which must be in the hand of the user when applying pesticides under state registrations. Consult supplemental labeling for additional use rate, drip application recommendations.</td>
</tr>
</tbody>
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This product is not as consistently effective against root-knot nematodes as the fumigants, but are registered as indicated.

Table 2. Fumigant nematicides for tomatoes, peppers and eggplants in Florida.

<table>
<thead>
<tr>
<th>Nematicide</th>
<th>Broadcast Application</th>
<th>In the Row Applications</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Gallons or Lbs Per acre</td>
<td>Fl oz/1000 ft/chisel spaced 12&quot; apart</td>
</tr>
<tr>
<td>Methyl Bromide Chloropicrin</td>
<td>A critical use exemption (CUE) for continuing use of methyl bromide for tomato, pepper, and eggplant has been awarded for calendar years 2009 and 2010. Specific certified uses and labeling requirements for CUE acquired methyl bromide must be satisfied prior to grower purchase and use in these crops. Quantity and formulation availability are subject to change.</td>
<td></td>
</tr>
<tr>
<td>Telone II</td>
<td>9 to 12 gal</td>
<td>26 to 35</td>
</tr>
<tr>
<td>Telone C-17</td>
<td>10.8 to 17.1 gal</td>
<td>31.8 to 50.2</td>
</tr>
<tr>
<td>Telone C-35</td>
<td>13 to 20.5 gal</td>
<td>38 to 60</td>
</tr>
<tr>
<td>Telone InLine</td>
<td>13 to 20.5 gal</td>
<td>-</td>
</tr>
<tr>
<td>Pic Chlor 60</td>
<td>19.5 - 31.5 gal</td>
<td>57 to 90</td>
</tr>
<tr>
<td>Pic Chlor 60 EC</td>
<td>19.5 - 31.5 gal</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 2. Fumigant nematicides for tomatoes, peppers and eggplants in Florida.

<table>
<thead>
<tr>
<th>Nematicide</th>
<th>Broadcast Application</th>
<th>In the Row Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gallons or Lbs Per acre</td>
<td>Fl oz/1000 ft/chisel spaced 12&quot; apart</td>
</tr>
<tr>
<td>Midas 98:2(^2,4)</td>
<td>100 - 175 lb (5.3 - 9.3 gal)</td>
<td>-</td>
</tr>
<tr>
<td>Midas 50:50(^2,4)</td>
<td>150 - 350 lb (9.4 - 22 gal)</td>
<td>-</td>
</tr>
<tr>
<td>Vapam HL</td>
<td>75 gal</td>
<td>-</td>
</tr>
<tr>
<td>KPam HL</td>
<td>60 gal</td>
<td>-</td>
</tr>
</tbody>
</table>

1 Gallons/acre and Fl oz / 1000 feet provided only for mineral soils. Higher rates may be possible for heavier textured (loam, silt, clay) or highly organic soils.
2 All of the fumigants mentioned are for retail sale and use only by state certified applicators or persons under their direct supervision. New supplemental labeling for the Telone products must be in the hands of the user at the time of application. See label details for additional use restrictions based on soil characteristics, buffer zones, and requirements for Personal Protective Equipment (PPE) and rate modifying recommendations with use of highly retentive mulch films.
3 Higher application rates are possible in the presence of cyst-forming nematodes.
4 Midas 98:2 and 50:50 for Tomatoes and Pepper only. Certification required for application.

Rates are believed to be correct for products named, and similar products of other brand names, when applied to mineral soils. Higher rates are required for muck (organic) soils. However, the grower has the final responsibility to see that each product is used legally; read the label of the product to be sure that you are using it properly.