Nematode Management in Beans and Peas (Bush Beans, Pole Beans, Lima Beans, Southern Peas, English Peas, Chinese or Snow Peas)[1]

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Beans and peas are grown throughout Florida. In sandy soils, they are often damaged by root-knot, sting, awl, and stubby-root nematodes. In rock-based (Dade Co.) and muck soils, root-knot and reinform nematodes are most important. Soil-borne diseases are often as important as nematodes, and chemical treatments are chosen as often to reduce losses to other pathogens as nematodes. The host range of these nematodes, as with others, includes many different weeds and 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 or bacterial pathogens or to transmit virus diseases, which contribute to additional yield reductions.

Multispectrum fumigants such as Vapam, Telone C-17, Telone C-35, and Pic Clor 60 are often used as row treatments to reduce both nematode and fungus losses. Relatively low label rates are sometimes adequate for nematode and disease suppression for snap beans because their short (45 to 60 days) growing season limits time for pest reproduction. Refer to the section on Fumigants for more complete discussion of their use.

General IPM Considerations

Integrated pest management (IPM) for nematodes requires 1) determining whether pathogenic nematodes are present within the field; 2) determining whether nematode population densities are high enough to cause economic loss; and 3) selecting a profitable management option. Attempts to manage nematodes may be unprofitable unless all of the above IPM procedures are considered and carefully followed. Similarly, some management methods pose risks to people and the environment. Therefore, it is important to know that their use is justified by actual conditions in a field and that certified applicators are overseeing their use.

Biology and 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 larva 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 some 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

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adult males or females. For most species of nematodes, as many as 50–100 eggs are produced per female, but in some 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 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 nonuniform growth rather than as an overall decline of plants within an entire field (Figure 1).

Figure 1. 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.

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 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 2). 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 2. Close-up view of root-knot nematode (*Meloidogyne* spp.) induced galling of plant roots. Note the enlarged, tumerous 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-knot 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 3). 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 and reproduction. At very high levels, typical of those that 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.

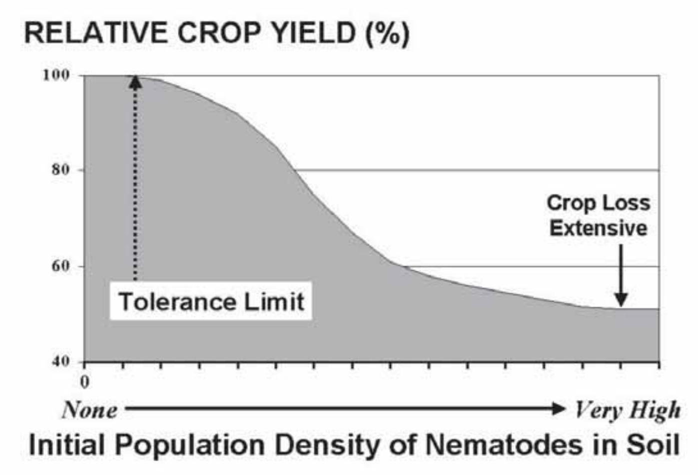

Figure 3. Typical nematode induced crop damage relationship in which crop yields, expressed as a percentage of yields that would be obtained in the absence of nematodes, decline with increased population density of nematodes in soil. The tolerance level is identified as the initial or minimal soil population density at which crop damage is first observed.

Field Diagnosis and 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 are preplant or postharvest considerations 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 4). Since most species of nematodes are concentrated in the crop rooting zone, samples should be collected to a soil depth of at least 6 to 10 inches. Plant-pathogenic nematodes such as sting and root-knot can be deeply distributed throughout the soil profile to a depth of 4 feet, however, well below the typical sampling depth and zones of root growth, and have the capability to move upward to infest plant roots. In this scenario, samples procured from surface soil horizons may not adequately describe nematode populations and potential threats to crop growth and yield. As a practical strategy, however, sample in a regular pattern over the area, emphasizing removal of samples across rows rather than along rows (Figure 5). 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 that have different crops (or varieties) during the past season or that 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 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 6).

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

Figure 4. The collection of soil samples for nematode analysis can be acquired from the field using cylindrical sampling tubes, a trowel, a bucket auger, or a shovel.

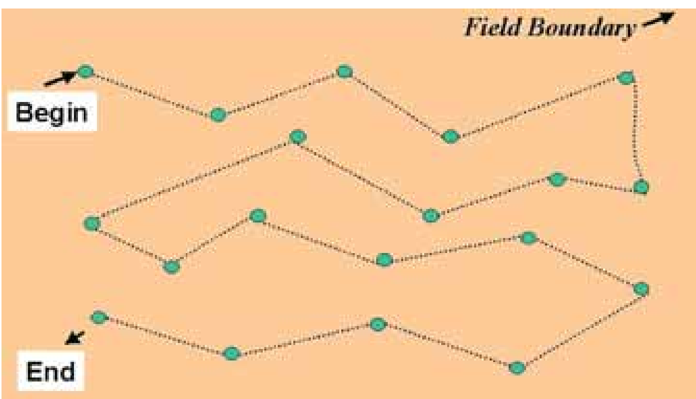

Figure 5. Suggested pattern for collecting preplant soil samples for nematode analysis based on compositing soil from 10–20 field locations.

Recognizing that the root-knot nematode causes the formation of large swollen knots 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 that 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 (Figure 7). In general, soil population levels increase with root gall severity (Figure 8). This form of sampling can in many cases provide immediate confirmation of a nematode problem and allows mapping of current field infestation.

Figure 6. Suggested strategy for collecting post-plant soil samples for nematode analysis comparing sampling results from areas of good and poor plant growth.

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 through 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. 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 that 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 beans and peas are soil applied,

Figure 7. Field diagnosis for the presence and severity of root-knot nematodes via visual examination of uprooted plant root systems for root galls.

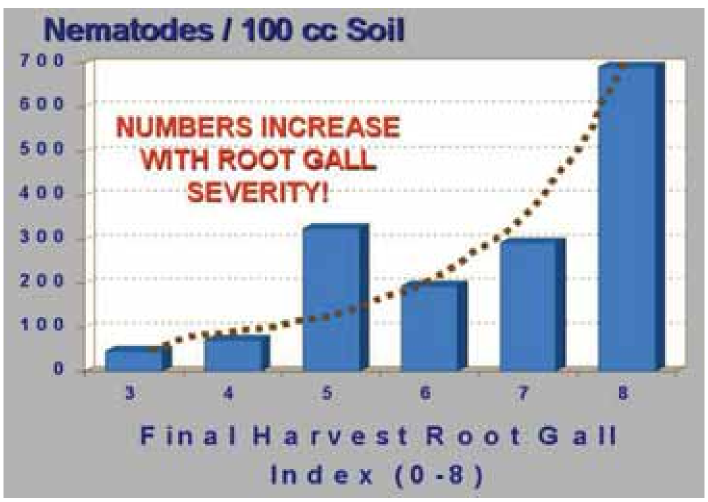

Figure 8. Generalized relationship between the number of root-knot nematode juveniles in soil based on the level and severity of plant root galling.

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 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 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 a broadspectrum fumigant nematicide. 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 (Tables 2 and 3) effectively reduces nematode populations and increases vegetable crop yields, particularly when compared with nonfumigant nematicides (Figure 9). Since these products must diffuse through soil as gases to be effective (Figure 10), 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 ensure decomposition of plant materials before attempting to fumigate.

In general, the use of soil fumigants has been more consistently effective than nonfumigants for control of root-knot and sting nematodes in Florida. In the fine sands of Florida, dry soils (no more than or less than 12 to 15% available soil moisture content) are considered favorable for soil fumigation. In addition to buffer zones, the new fumigant labels also outline a new series of mandatory Good Agricultural Practices (GAPs) to reduce emissions and bystander exposures. These have become new mandatory label requirements effective January 1, 2012. The new GAPs must be followed during all fumigant applications and that are posing Florida growers significant difficulties include changes in 1) Soil Preparation: "Soil shall be properly prepared" and "field trash must be properly managed." Residue from a previous crop must be worked into the soil to allow for decomposition prior to fumigation.; 2) Soil Moisture: In general, the new soil fumigant labels will indicate that soil moisture in the top nine inches of soil must be between 50% to 80% of soil capacity (field capacity) immediately prior to fumigant application, subject to the exception where soil moisture must exceed field capacity to form a bed (e.g., certain regions in Florida where soil capacity may exceed the 80% allocated above). Following EPA reregistration, the new fumigant labels that went into effect December 1, 2012, detail additional use restrictions based on soil characteristics, buffer zones, requirements for Personal Protective Equipment (PPE), mandatory good agricultural practices (GAPs), applicator training certification, and other new rate modifying recommendations.

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 11 and Figure 12). Field observations also suggest rainfall or irrigation that saturates the soil after treatment tends to retain phytotoxic residues for longer periods, particularly in deeper soil layers.

Figure 9. Preplant soil fumigation for nematode control.

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 practicality 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

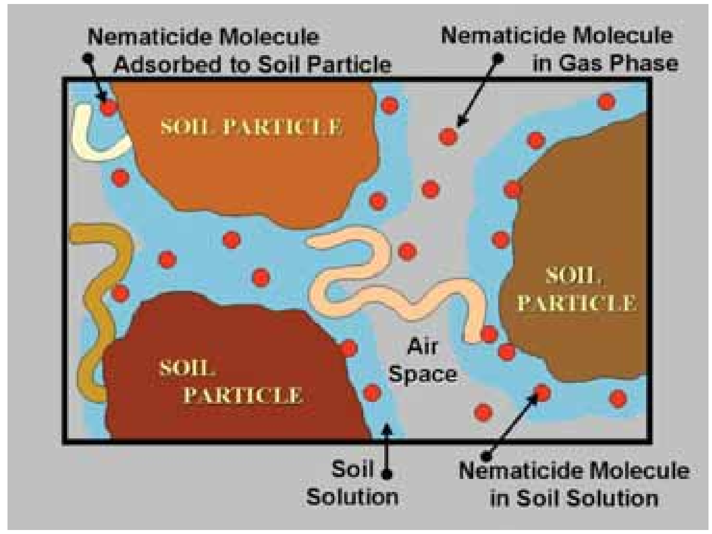

Figure 10. Nematode as aquatic organisms encountering both liquid and gas phase nematicides in soil.

Figure 11. Sweet corn phytotoxicity to post treatment soil residuals of metham sodium.

other pests can cause crop damage and yield losses that 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.

Nonfumigant nematicides listed in Table 1 have not been as reliable against root nematodes as fumigants, but may be effective against other nematodes under some conditions. Fumigant nematicides listed in Table 2 are most reliable for reduction of root nematodes.

Figure 12. Crop phytotoxicity of tomato to post treatment soil residuals of 1,3 dichloropropene.

Table 1. Nonfumigant nematicides for beans and peas in Florida.

Product	Broadcast or overall rates		Row rates	
	Per acre	Per 1000 sq ft	Per acre, 36” row spacing	Per 1000 ft of row, any row spacing
Mocap 15G*	40–54 lb	0.9–1.2 lb	13 to 20 lb	0.9 to 1.4 lb
* Snap and lima bean only. Do not use as a seed furrow treatment or allow products to contact seed. Apply Mocap products in a 12 to 15 inch band at planting, incorporating to a soil depth of 2 to 4 inches.				
These products are not as consistently effective against root knot nematodes as the fumigants, but are registered as indicated.				

Table 2. Fumigant nematicides for beans and peas in Florida.

Nematicide	Broadcast application [1]	In the row applications	
	Gallons or lbs per acre	Fl oz /1000 ft / chisel spaced 12” apart	
Telone II [2,3]	9 to 12 gal	26 to 35	For any row spacing, application rates given may be concentrated in the row, but shall never exceed the labeled maximum for broadcast applications. Consult the product label for additional detail.
Telone C-17 [2,3]	10.8 to 17.1 gal	31.8 to 50.2	For any row spacing, application rates given may be concentrated in the row, but shall never exceed the labeled maximum for broadcast applications. Consult the product label for additional detail.
Telone C-35 [2,3]	13 to 20.5	38.2 to 60.2	For any row spacing, application rates given may be concentrated in the row, but shall never exceed the labeled maximum for broadcast applications. Consult the product label for additional detail.
Pic-Clor 60	19 to 31.5	57 to 90	For any row spacing, application rates should never exceed the labeled maximum for broadcast applications. Consult the product label for additional detail.
Vapam HL	75 gal	–	For drip or in row fumigation, consult product label for proportionately reduced overall rates, drip concentration and flow modifying directions and procedures.
KPam HL	60 gal	–	For drip or in-row fumigation, consult product label for proportionately reduced overall rates, drip concentration and flow modifying directions.
Allyl isothiocyanate (AITC) Dominus	40 gal	–	For drip or in-row fumigation and crop termination, consult product label for proportionately reduced overall rates, drip concentration and flow modifying directions
[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, requirement for Personal Protective Equipment (PPE), mandatory good agricultural practices (GAPs), product and applicator training certification, and other rate modifying recommendations which may be required. [3]Higher application rates are possible in the presence of cyst-forming nematodes.			
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.			

Table 3. Generalized summary of maximum use rate and relative effectiveness of various soil fumigants for nematode, soilborne disease, and weed control in Florida.

FUMIGANT CHEMICAL[1]	Maximum Use Rate / A	Relative Pesticidal Activity		
		Nematode	Disease	Weed
1) Chloropicrin[2]	300 lb	None to Poor	Excellent	Poor
2) Metam Sodium	75 gal	Good to Poor	Good to Poor	Good to Poor
3) Telone II	18 gal	Good to Excellent	None to Poor	Poor
4) Telone C17	26 gal	Good to Excellent	Good	Poor
5) Telone C35	35 gal	Good to Excellent	Good to Excellent	Poor to Fair
6) Pic-Clor 60	300 lb	Good to Excellent	Good to Excellent	Poor to Fair
7) Metam Potassium	60 gal	Good to Poor	Good to Poor	Good to Poor
8) Dimethyl Disulfide[2]	53 gal	Good to Excellent	Good to Excellent	Poor to Excellent
9) AITC (Dominus)	40 gal	Still in assessment	Still in assessment	Still in assessment

[1] Use of soil fumigants in Florida now requires new fumigant product and applicator training certifications, personal protective equipment, buffer zones, mandatory good application practices, and other new restrictions and requirements.

[2] Broad spectrum pest control achieved when coapplied with chloropicrin (21% wt/wt). Provides excellent control of nutsedge but poor to fair control of annual grasses and requires the use of a herbicide for adequate control. DMDS (Paladin) is currently not registered for beans and peas in Florida.

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