Chemical Nematicides
FOR CONTROL OF PLANT-PARASITIC NEMATODES
in Georgia Vegetable Crops

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Georgia is among the top-four producers of fresh vegetable crops in the U.S. Major vegetable production is located in multiple counties (Table 1) in the southern part of the state. Vegetables are grown year-round on both raised beds covered with polyethylene plastic mulch and on bare ground. Some commercial growers that produce vegetables on bare ground include rotation with other annual or row crops such as cotton or field corn in their cultivation systems. Polyethylene mulch (including black, clear, and white-on-black plastics) increases growth by enhancing temperature absorption and retention of soil moisture. Nearly one-third of the total vegetable production in the state of Georgia is plasticulture. This cultivation system is primarily used in the production of tomatoes, eggplants, cabbage, squash, zucchinis, cucumbers, watermelons, cantaloupes, and bell peppers. However, extensive cultivation of vegetables on plastic mulch can increase the risk of problems with soilborne pests and pathogens including plant-parasitic nematodes. This is particularly important in the second or third crop grown on the same plastic mulch because reusing the mulch favors the buildup of populations of these pathogens in soil. In fact, crop damage is often increased when two crops of vegetables are grown every year. Many root diseases, including those caused by plant-parasitic nematodes, are widely distributed in Georgia's soil and hinder the production of vegetables. Plant-parasitic nematodes cause root injury throughout the growing season and leads to severe yield losses. The impact of nematodes is more severe in sandy soils, which are common in southern Georgia. Sandy soils have large pore spaces that favor nematode movement to locate and feed on the roots of host plants. For more information on how to identify problems with plant-parasitic nematodes in vegetable production systems, refer to University of Georgia Cooperative Extension Circular 1126, which can be found at http://extension.uga.edu/publications/detail.html?number=C1126.

Table 1. Leading Georgia counties for vegetable crops in 2017 (Georgia Farm Gate Value Report).

Crop	Leading counties
Onion	Tattnall, Toombs
Bell pepper	Echols, Colquitt, Brooks
Cantaloupe	Tift, Colquitt, Worth
Cucumber	Brooks, Dodge, Colquitt
Cabbage	Colquitt, Toombs, Tift
Eggplant	Echols, Colquitt, Brooks
Greens	Tift, Colquitt, Toombs
Squash	Echols, Colquitt
Snap bean	Echols, Sumter
Watermelon	Crisp, Tift
Tomato	Decatur, Rabun, Colquitt
Zucchini	Colquitt, Tift

Several management practices can be used to combat nematode diseases in vegetables. These include cultural, chemical, and biological controls as well as host resistance. Control practices such as rotations to nonhost crops in plasticulture systems are limited because two or more vegetable crops are often grown on the same land each year, or in two consecutive years, and this restricts rotational cycles. Moreover, few nematode-resistant varieties of vegetables are commercially available. In such production systems, effective management of plant-parasitic nematodes has relied upon the application of chemical nematicides as a short-term control means by suppressing nematode population densities in soil to levels below known economic damage thresholds. The reduction of nematode population densities to below threshold levels will reduce their damage to roots and increase yield in infested fields. Chemical nematicides have been used singly or in combination with other nematode control practices since the late 19th century. The use of nematicides is globally valued at about $1 billion annually, with 48% of this market being spent for the control of root-knot nematodes.

Types of nematicides

Nematicides are chemically synthesized products that kill nematodes or adversely affect nematodes. These products can have nematicidal or nemastatic effects against nematodes. Nematicidal compounds are highly toxic and kill exposed nematodes, whereas nemastatic compounds do not kill nematodes but impede nematode movement toward host plant roots or delay nematode egg hatching. In this publication, the term "nematicide" will be used to describe any compound that is used for control of nematode diseases in vegetables. Nematicides are grouped into fumigant and non-fumigant nematicides based on their volatility in soil.

Fumigant nematicides

Fumigant nematicides are toxic compounds with narrow- to broad-spectrum effects. In addition to killing plant-parasitic nematodes, they may also be effective against numerous types of soilborne pests and pathogens. Fumigants are used to disinfest soil and reduce the risk of yield loss caused by soilborne pests in high-value crops such as vegetables. When applied to the soil, fumigant compounds reach target organisms in the form of gas that moves through the open spaces between soil particles or by dissolving into the film of water that surrounds soil particles. Treating soil with fumigant nematicides can effectively control plant-parasitic nematodes over a range of soil types, but they are generally more effective in coarse-textured (sandy) soils than in fine-textured (clay) soils. The gaseous dispersal of fumigants may also be constrained in soils with water-filled pore space. Additionally, the volatility of fumigants is affected by soil temperature: volatility is higher in warm soils and lower in cool soils. For example, Telone II (1,3-dichloropropene) has promising nematicidal efficacy when injected into soil at soil temperatures ranging from 40 to 80 ˚F. Additionally, adequate soil moisture is necessary for proper movement of the gases in the soil. Excessive soil moisture, therefore, will reduce the efficacy of the fumigant nematicides.

For decades, soil fumigation has played a crucial role in controlling nematodes in the production of vegetable crops throughout the U.S., including Georgia. Prior to 2005, chemical control options for soilborne nematodes, pathogens, and weeds were rather limited to methyl bromide, which provided a high level of control of various pathogens and pests. Following the methyl bromide phaseout initiated in January 2005 under the provisions of the U.S. Clean Air Act and the Montreal Protocol due to its ozone depletion effects, attention has focused on the application of other chemistries for the short-term management of nematodes.

Managing the root-knot nematode (*Meloidogyne* spp.) is very important to vegetable production in Georgia. The root-knot nematode is the most critical yield-limiting nematode pathogen to multiple vegetable crops and they are widely distributed in most of the vegetable-growing regions in the state. More than 50% of all vegetable fields have at least one *Meloidogyne* species above the known damage threshold level. Sandy soils, which are common in southern Georgia, favor the establishment and development of root-knot nematodes, but they also are well aerated and drained, which increases the efficacy of soil fumigants. In fact, preplant soil fumigation of infested soil is the dominant approach for managing root-knot nematodes in vegetable crops. Fumigant nematicides are applied to the soil with fumigation equipment that injects the material into soil and covers the soil with a polyethylene mulch in one operation. Transplanting vegetable seedlings into treated beds usually occurs two to three weeks after fumigation, depending on the fumigant type and rate, soil moisture, and soil temperature, when nematodes have been killed and all residues of fumigant nematicides have adequately dispersed. Chemical fumigants are highly effective in reducing nematode populations in soil. However, major drawbacks of these compounds are that they are difficult to apply, have a long re-entry period compared with non-fumigants, require buffer zones, and are rather expensive. It is also important to know that soil fumigation will not completely kill all plant-parasitic nematodes when applied inaccurately. The aim of soil treatments with fumigants is to reduce population densities of nematodes to allow for successful plant establishment and growth.

Several fumigant nematicides (Table 2) are available for use against plant-parasitic nematodes. The most common fumigants used to control nematodes in vegetable crops in Georgia are Telone II, chloropicrin, Vapam (metam sodium), and Paladin (dimethyl disulfide or DMDS).

Table 2. Chemical fumigant nematicides currently available for use in vegetable production.*

Trade Name	Active Ingredient	Toxic Activity	Manufacturer
Telone II	1,3 dichloropropene (1,3-D)	Nematicide	Corteva Agriscience™, Agriculture Division of DowDuPont™
Chlor-O-Pic	96.5-99% chloropicrin	Nematicide/Fungicide	Corteva Agriscience™, Agriculture Division of DowDuPont™
Telone C-17	73% 1,3-D, 17% chloropicrin	Nematicide/Fungicide	Corteva Agriscience™, Agriculture Division of DowDuPont™
Telone C-35	65% 1,3-D, 35% chloropicrin	Nematicide/Fungicide	Corteva Agriscience™, Agriculture Division of DowDuPont™
Telone EC	1,3-D	Nematicide	Corteva Agriscience™, Agriculture Division of DowDuPont™
InLine	61% 1,3-D, 33% chloropicrin	Nematicide/Fungicide	Corteva Agriscience™, Agriculture Division of DowDuPont™
PicClor-60	40% 1,3-D, 60% chloropicrin	Nematicide/Fungicide	Corteva Agriscience™, Agriculture Division of DowDuPont™
Vapam	Metam sodium	Broad-spectrum	AMVAC Chemical Corporation
K-Pam	Metam potassium	Broad-spectrum	AMVAC Chemical Corporation
Paladin	Dimethyl Disulfide	Broad-spectrum	Arkema Inc.
Dominus	Allyl isothiocyanate	Broad-spectrum	Isagro USA

*Consult your county Extension agent or the Georgia Pest Management Handbook for recommendations on application rates and preplant intervals.

Telone II

The nematicidal properties of Telone II were discovered in 1943, but its commercial application to control root diseases caused by nematodes increased much later, when other fumigants such as ethylene dibromide and methyl bromide were taken off the market. Indeed, Telone II became more popular for nematode control after methyl bromide began to be phased out in 2005 and vegetable producers had to apply alternatives. Telone II has been demonstrated nationally and globally to increase crop yields in nematode-infested fields at ranges relatively comparable to methyl bromide. Currently, it is the most commonly used fumigant in plasticulture and bare ground production systems in the Southeastern U.S. With the limited use of Telone II in the near future due to potential environmental concerns, there will be few alternatives available to control nematodes of economic importance. This will have a considerable impact on Georgia's vegetable production.

Chloropicrin

Chloropicrin has been used as preplant soil fumigant for control of nematodes and soilborne diseases in various crops since 1919 in the U.S. It is manufactured in liquid form with a moderate vapor pressure and it disperses quickly through soil when applied below the soil surface under a tarp. The nematicidal effect of chloropicrin is not the primary reason for its application, as it also has fungicidal, insecticidal, and herbicidal activity, making it a broad-spectrum biocide. Chloropicrin is often used in combination with 1,3-D to fumigate soil, and formulations of chloropicrin that include 1,3-D (e.g., Telone C-17 and Telone C-35) increase the nematicidal effect of chloropicrin. Such mixtures control both nematodes and other pathogens better than either product alone.

Vapam

Vapam (a methyl isothiocyanate generator) is a liquid product that has a slow nematicidal effect compared with Telone II. This product can be applied by drenching, spraying, or injection procedures. Vapam lacks consistent performance in the control of nematodes, therefore growers do not extensively use it as a single management option. However, research suggests that effective control of root-knot nematodes can be achieved when Vapam is combined with non-fumigant nematicides. This nematicide also has some toxicity effect on weeds at higher rates.

Paladin

Paladin has been recently marketed in the U.S. as a soil fumigant to control nematodes, weeds, and soilborne plant pathogens. As an emulsified compound, Paladin may be broadcast, drenched, or drip-applied prior to planting for control of soilborne pests in vegetables crops including tomatoes, cucurbits, squash, peppers, eggplants, and melons.

Non-fumigant nematicides

Non-fumigant nematicides are nonvolatile toxic chemicals that can be applied prior to planting, at planting, or after planting through soil drenching, drip irrigation, or spraying onto the crop foliage to reduce population densities of nematodes and protect crops from damage. These products are grouped into two categories: contact (killing nematodes in soil by direct exposure) or systemic (killing nematodes while they feed from plant roots) nematicides. When applied to the soil, non-fumigant compounds are dispersed by movement in soil water. In contrast to fumigant nematicides, the efficacy of non-fumigants does not depend on soil temperature. A major drawback of these compounds is that their efficacy is generally less than that of fumigants such as Telone II for nematode control. Quick leaching of the active ingredients of non-fumigants, particularly in sandy soils, may also reduce their effectiveness. The removal of many older non-fumigant nematicides from the market due to toxicity and environmental concerns has encouraged the development of a new generation of chemical compounds that address these concerns and offer effective nematode management. A few non-fumigant nematicides are commercially available for use in vegetable crops (Table 3).

Table 3. Chemical non-fumigant nematicides currently available for use in vegetable production.*

Trade Name	Active Ingredient	Toxic Activity	Manufacturer
Vydate (L, C, LV)	Oxamyl	Nematicide/Insecticide	Corteva AgriscienceTM, Agriculture Division of DowDuPont™
Nimitz	Fluensulfone	Nematicide	Adama
Velum Prime	Fluopyram	Nematicide/Fungicide	Bayer CropScience
Mocap 15G	Ethoprop	Nematicide/Insecticide	AMVAC Chemical Corporation
Mocap EC	Ethoprop	Nematicide/Insecticide	AMVAC Chemical Corporation
Movento	Spirotetramat	Nematicide/Insecticide	Bayer CropScience
Counter 20G	Terbufos	Nematicide/Insecticide	AMVAC Chemical Corporation
Salibro**	Fluazaindolizine	Nematicide	Corteva AgriscienceTM, Agriculture Division of DowDuPont™

*Consult your county Extension agent or the Georgia Pest Management Handbook for recommendations for application rates and preplant intervals. For a complete list of appropriate crops, please consult the label.

**This nematicide has not yet been registered for use at the time of publication of this note (December 2018).

Vydate

Vydate® is a carbamate (a pesticide derived from carbamic acid) that has nematicidal and insecticidal properties against plant-parasitic nematodes and soil insects. Vydate is a systemic nematicide (any compound that can be taken up by the plant through roots, leaves or both, and is effective against nematodes inside the plant), and is used in liquid form, as the granular form is no longer labeled in the U.S. due to concerns regarding its consumption by birds. This nematicide may be applied before planting, at planting, and after planting through soil drench, in-furrow, drip injection, broadcast, or foliar spray. Vydate is effective against nematodes in carrots, cucumbers, tomatoes, eggplants, squash, peppers, watermelon, and cantaloupes.

Nimitz

Nimitz® is a systemic fluoroalkenyl compound that recently received U.S. Environmental Protection Agency (EPA) registration for use in vegetable crops. In vegetable production systems, Nimitz has received much interest as a methyl bromide alternative in part because it causes mortality of target nematodes within 24 to 48 hours of product application. This nematicide controls several types of plant-parasitic nematodes (e.g., root-knot, stubby root, sting, lesion, and needle nematodes) resulting in improved fruit quality and yield of

several vegetable crops, including cucumbers, eggplants, tomatoes, and peppers. Nimitz can be broadcast or applied through drip irrigation seven days before seeding or transplanting vegetables. Nimitz has shown the greatest efficacy in the control of plant-parasitic nematodes when used preplant. When applied on plant foliage, the active ingredient of Nimitz moves from the application point down into the roots, where it might affect parasitic nematodes. To prevent phytotoxicity and subsequent crop losses, foliar application of Nimitz is not recommended.

Velum Prime

Velum Prime® is manufactured as a liquid formulation and is one of the few available non-fumigant nematicides with systemic properties labeled for control of multiple species of plant-parasitic nematodes in the Southern U.S. This nematicide can be broadcast or applied through soil drench and drip irrigation at planting of vegetables. Velum Prime is registered for vegetable crops including potatoes and sweet potatoes; cucurbit vegetables such as cucumbers, pickling cucumbers, squash, watermelons, and cantaloupes; fruiting vegetables such as tomatoes, eggplants, okra, and peppers; and brassica vegetables such as cabbage and broccoli.

Mocap

Mocap® is a granular (15G) or liquid (EC) systemic insecticide/nematicide containing ethoprophos, which is used to reduce plant-parasitic nematode damage in some vegetable crops, including potatoes, sweet potatoes, cucumbers, corn (sweet and field), and cabbage. The nematicidal activity of Mocap can be achieved before or at planting by band or broadcast application.

Movento

Movento® is currently registered as a liquid formulation with potential to control both plant-parasitic nematodes and insect pests. It can be applied as a soil or plant foliage spray or through chemigation. Once applied on the plant foliage, the systemic activity of the product will allow it to penetrate the leaf surface and translocate down within plant tissues toward the roots, where most parasitic species of nematodes feed. This nematicide has shown some beneficial activity when used against root-knot nematodes in carrots and sweet potatoes.

Counter

Counter® 20G is a granular systemic insecticide and nematicide that is registered for the control of plant-parasitic nematodes in sweet corn. This nematicide can be applied in-furrow or banded at planting using the Lock'n Load handling system because of its high toxicity.

Fluazaindolizine

Fluazaindolizine is a new effective and selective nematicide for the control of nematodes, but it has not yet been registered for use in the U.S. Over several years, fluazaindolizine has been tested in the U.S. in field trials against nematodes including root-knot nematodes, and it has shown good nematicidal effect when used at planting. If registered, this chemical could be a promising product to control nematodes in vegetable crops, and because it does not affect beneficial organisms in the soil, it could be considered for integrated pest management programs of specialty crops.

Important considerations to get the most benefits from nematicides:

- Know the present type of plant-parasitic nematodes and their population densities in soil.
- Know the application rate, application depth, and time intervals before planting. This information can be found on nematicide label directions and should be followed carefully before applying nematicides.
- Know how to calibrate a nematicide applicator to correctly deliver the recommended rate.
- Know the environmental and soil conditions (soil temperature, soil moisture, rainfall, and wind speed) before applying nematicides. Nematicides should not be used if heavy rainfall is forecast to occur within 48-72 hours.

Summary

Soil fumigants alone or in combination with non-fumigant nematicides can provide vegetable growers effective and reliable control options for plant-parasitic nematodes, profitable yield and product quality, and increased profits. Treating soil with fumigant nematicides has been very beneficial to vegetable growers in Georgia, but environmental concerns may restrict the broad usage of these products. Telone II has been an important nematode management tool for the field production of many vegetable crops. Vegetable growers will have very limited options if soil fumigants, in particular Telone II, are no longer available. The development of new effective and environmentally safe non-fumigant nematicides has reduced the dependency on fumigant nematicides, but the application of fumigants still has great value for growers in Georgia.

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