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Managing Root-knot on Tobacco in the Southeastern United States

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Abstract: Root-knot nematodes suppress yields of flue-cured tobacco an estimated 0.1 to 4.8% annually in the southeastern United States, even though nematode management practices have been widely adopted. Although *Meloidogyne incognita* races 1 and 3 have predominated, *M. arenaria, M. javanica,* and *M. incognita* races 2 and 4 are increasingly important. Seventy-five percent of the flue-cured tobacco hectarage in North Carolina and Virginia is rotated on 2-year or 3-year intervals. Over half of the hectarage in the southeastern United States was planted with tobacco cultivars resistant to *M. incognita* races 1 and 3 in 1986. Resistance to other species or races of root-knot nematodes is not available in commercially available flue-cured tobacco cultivars. Most producers plow and (or) disc-out flue-cured tobacco roots and stalks after harvest. Nematicide use ranges from virtually 100% in Florida and Georgia to 60% in Virginia. Continued research is needed to develop management strategies for mixed populations of root-knot nematodes and to incorporate resistance to more root-knot nematode species and races into tobacco cultivars. Nematode advisory programs that allow producers to optimize nematicide use from an economical and ecological point of view are also needed.
Key words: chemical control, crop loss, crop rotation, cultural practice, integrated pest management, *Meloidogyne* spp., nematicide, nematode advisory service, *Nicotiana tabacum,* resistance, root-knot nematode, tobacco.

Root-knot nematodes are among the most serious pests of flue-cured tobacco (*Nicotiana tabacum* L.) in the southeastern United States. Species of root-knot nematodes associated with flue-cured tobacco in this region include *Meloidogyne arenaria* (Neal) Chitwood, *M. hapla* Chitwood, *M. incognita* (Kofoid & White) Chitwood, and *M. javanica* (Treub) Chitwood (5). *Meloidogyne javanica* is the major root-knot nematode species infesting flue-cured tobacco fields in Florida (20). *Meloidogyne arenaria* and *M. incognita* are the major species in Georgia, although *M. javanica* also occurs (A. S. Csinos, pers. comm.). Schmitt and Barker (22) found that 60% of the flue-cured tobacco fields in North Carolina were infested with root-knot nematodes. Although *M. incognita* races 1 and 3 predominate in flue-cured tobacco fields in North and South Carolina, the increased incidence of *M. arenaria* and *M. javanica* (10,11) is alarming because these species are even more aggressive on flue-cured tobacco than *M. incognita* races 1 and 3 (1,5).

Although nematode management practices are widely used in the southeastern United States, annual estimates of nematode damage to flue-cured tobacco have ranged from 0.1 to 4.8% of the total gross value of the crop (2). These estimates represent an approximate 10-fold reduction from losses experienced before the widespread adoption of root-knot nematode management practices such as resistant cultivars, nematicides, etc. (15). While current estimates of percentage of loss to root-knot nematodes may not appear large, the high economic value of flue-cured tobacco translates low percentages of crop loss into millions of dollars. For example, 1% loss due to root-knot in North Carolina tobacco fields in 1988 resulted in an estimated loss of $8,649,000 (16). Actual losses due to root-knot after attempted management may also be routinely underestimated. Nematode management costs are not included in most estimates of crop loss, even though such costs can be directly related to the incidence and severity of plant-parasitic nematode infestations. In addition, some symptoms of nematode parasitism, such as reduced crop vigor, are not as eye-

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TABLE 1. Effects of 2-year crop rotations on galling and yield of flue-cured tobacco in North Carolina in 1964.†

County	Alternate crop	Gall index‡	Yield (kg/ha)
Johnson	Tobacco	37.1	2,422
	Corn	30.7	2,557
	Small grain (fescue)	14.8	2,929
Martin	Tobacco	66.3	1,426
	Corn	47.5	2,197
	Small grain (fescue)	7.5	2,326

† Data from Todd et al. (28).
‡ Gall index: 0 = no galls; 100 = maximum development. All observations based on 500 cm³ soil.

TABLE 2. Effects of early root and stalk destruction on galling of flue-cured tobacco in four different seasons.†

Year	Roots plowed-out	Cover crop planted	Gall index‡	Root-knot nematodes/ 500 cm³ soil
1964	No	No	57	35,091
	Yes	No	53	15,833
	Yes	Yes	49	19,058
1967	No	No	11	2,575
	Yes	No	0	12
	Yes	Yes	0	0
1970	No	No	46	13,775
	Yes	No	3	2,250
	Yes	Yes	0	138
1973	No	No	44	—§
	Yes	No	37	—
	Yes	Yes	9	—

† Data from Todd et al. (26–29).
‡ Gall index: 0 = no galls; 100 = maximum development. All observations based on 500 cm³ soil.
§ Data not available.

catching in the more northern regions of the flue-cured tobacco producing area as the plant mortality caused by other important tobacco diseases. Consequently, as high as current estimates are for crop losses in flue-cured tobacco due to root-knot nematodes, the losses experienced by tobacco producers in the southeastern United States could be much higher.

Management of root-knot nematodes on flue-cured tobacco in the southeastern United States depends on crop rotation, destruction of tobacco roots and stalks as soon as possible after final harvest, resistant cultivars, and use of nematicides. Trends in specific root-knot management practices, particularly in nematicide use, vary across the flue-cured tobacco production region, depending upon the suitability of the soil environment for *Meloidogyne* species and the predominant species of root-knot nematode in the region.

Crop rotation effectively reduces population densities of root-knot nematodes and improves yields in flue-cured tobacco fields (Table 1) (7,12,21,28). However, rotation intervals required for acceptable root-knot control by crop rotation alone are longer than most producers can afford (15). The high economic value of flue-cured tobacco, relative to available alternative crops, forces most producers to use fairly short rotation intervals—generally no longer than 3 years (16, unpubl. data). Surveys conducted in North Carolina and Virginia for the 1986 growing season indicated that approximately 20% of the hectarage in each state was planted continuously to flue-cured tobacco, 75% of the hectarage was being rotated on 2-year or 3-year intervals, and rotation intervals of 4 years or longer were used for 3–7% of the flue-cured tobacco hectarage in the two states (18, unpubl. data). Recent federal programs seeking to reduce soil erosion and protect wetlands, etc., may increase the proportion of rotated hectarage and the rotation interval used.

Destruction of flue-cured tobacco roots and stalks as soon as possible after final harvest significantly improves control of root-knot nematodes (Table 2) (26–29). This practice also enhances control of tobacco insects and other tobacco diseases (15). As currently practiced, early root and stalk destruction involves cutting stalks and plowing or discing-out tobacco roots, discing the field again ca. 2 weeks after the roots have been plowed out of the soil, and planting a cover crop after tobacco roots have dried out and died. Use of early root and stalk destruction is thought to range from 95 to 99% of the producers in the Carolinas and Virginia (B. A. Fortnum and T. A. Melton, pers. comm.; unpubl. data). Apparently, fewer Florida and Georgia growers use this practice (A. S. Csinos and J. R. Rich, pers. comm.).

Flue-cured tobacco cultivars with resistance to *M. incognita* races 1 and 3 have been available since the release of 'NC 95' in 1961. In 1986 in Florida, Georgia, South Carolina, North Carolina, and Virginia, ca. 85, 50, 60–70, 75, and 65%, respectively, of the flue-cured tobacco hectarage was planted to cultivars resistant to these nematodes (18; J. R. Rich, A. S. Csinos, B. A. Fortnum, pers. comm.; unpubl. data). This resistance is conditioned by a single dominant gene pair transferred into commercial cultivars from *N. tomentosa* Ruiz & Pavon or a closely related *Nicotiana* species (24). The widespread use of root-knot resistance may be attributed to the successful incorporation of resistance into agronomically superior flue-cured tobacco, as well as to the emphasis that tobacco growers in the United States put on control of root-knot nematodes. High percentage-use figures in the United States reflect the exceptional popularity of the flue-cured tobacco cultivar K 326. This cultivar exhibits high yield and quality characteristics and has occupied over 50% of the flue-cured tobacco acreage in the United States since its release in 1984. Although some of the high productivity of this cultivar may be due to its root-knot resistance, a significant percentage of use is related to its other agronomic qualities.

Unfortunately, all flue-cured tobacco cultivars with resistance to *M. incognita* races 1 and 3 are susceptible to *M. arenaria, M. javanica,* and *M. incognita* races 2 and 4 (5). Research in South Carolina suggests that root-knot susceptible cultivars can be used to favor *M. incognita* races 1 and 3 over *M. arenaria* (25). Further research is needed on controlling mixed populations of *Meloidogyne* spp. by managing use of resistance to *M. incognita* races 1 and 3. No sources of resistance to other species and races of root-knot nematodes have been found within *N. tabacum,* but some success has been achieved in locating resistance in wild species of tobacco (8,9,17,23). However, the partial resistance to *M. arenaria* and *M. javanica* found in *N. repanda* Willd. and *N. longiflora* Cav. appears to decrease in proportion to the number of backcrosses to *N. tabacum* (17,23). Even so, interspecific crosses have been made and promising breeding lines have been identified for development of flue-cured tobacco cultivars with resistance to *M. incognita, M. arenaria,* and *M. javanica* (8,9). Incorporating resistance to *M. arenaria, M. javanica,* and *M. incognita* races 2 and 4, into agronomically acceptable flue-cured tobacco is another major challenge to improving root-knot nematode management.

Although cultural practices and host resistance significantly increase control of root-knot nematodes on flue-cured tobacco, many U.S. producers must rely on nematicides to maintain profitable yields and tobacco quality. Fumigant and nonfumigant nematicides are applied to 65 and 30%, respectively, of the flue-cured tobacco fields in Florida (J. R. Rich, pers. comm.). In contrast, 92, 80, 54, and 59% of the flue-cured tobacco produced in Georgia, South Carolina, North Carolina, and Virginia, respectively, is treated with nonfumigant nematicides (19; A. S. Csinos and B. A. Fortnum, pers. comm.; unpubl. data). Less than 10% of the flue-cured tobacco hectarage in Georgia, South Carolina, and Virginia is fumigated (A. S. Csinos and B. A. Fortnum, pers. comm; unpubl. data). Twenty percent of the flue-cured tobacco hectarage in North Carolina is fumigated, but a significant proportion of these applications are made for control of nematode-disease complexes involving wilt diseases such as Granville wilt (*Pseudomonas solanacearum* (Smith) Smith) or black shank (*Phytophthora parasitica* Dast, var. *nicotianae* (Breda de Haan) Tucker) (19). The smaller proportional use of nematicides in North Carolina and Virginia relative to the other states may reflect changes in the incidence of root-knot nematodes in flue-cured tobacco fields. The much higher use of fumigant nematicides in Florida, relative to the other flue-cured tobacco producing states, reflects a more favorable environment for nematodes in general, as well as the relatively high incidence of *M. javanica* in Florida.

Political and economic pressure to reduce and (or) optimize use of nematicides is another major challenge. All of the flue-cured tobacco producing states in the southeastern United States maintain active nematode assay services for growers; however, few producers take advantage of these programs. Ten percent or less of flue-cured tobacco producers typically use nematode assay services in Florida, Georgia, South Carolina, and Virginia (J. R. Rich, A. S. Csinos, and B. A. Fortnum, pers. comm.; unpubl. data). Approximately 20% of North Carolina flue-cured tobacco producers are thought to participate in a nematode assay program (13; T. A. Melton, pers. comm.). Barker and Imbriani (3), citing unpublished work by G. A. Carlson, suggested that the most common reason for nonparticipation in the North Carolina nematode assay program was a belief that nematodes did not significantly damage a particular farmer's crop. Routine pesticide application was ranked second as a reason for not submitting soil samples for nematode analysis, with unawareness of the assay program ranked third.

Pesticide reliability, the high economic value of flue-cured tobacco, and the conservative nature of farmers (i.e., their aversion to risk) are frequently cited as reasons for routine use of pesticides. These conclusions, however, may sidestep the issue of why farmers perceive use of a nematode assay as risky behavior and why their apparent assessment of the risk–benefit relationship for nematode assay participation seems so low. One possible reason for this apparent lack of faith in the reliability of nematode assay results may be a recognition by farmers, and particularly by county extension agents, of the imprecision in quantitative nematode population density estimates made from bulk samples taken from only a limited number of sample sites within a field (4,14). The labor involved in adequately sampling fields for nematode analyses has also been cited as a reason why many farmers seem unwilling to submit soil samples for nematode analyses. However, tobacco farmers in the United States have adopted other new and equally laborious production practices quite eagerly within recent years. Clipping plant beds and greenhouse transplant production are two examples.

Development of more precise nematode assay programs that United States tobacco farmers will participate in is one of the major challenges for the future. Recent work on management of root-knot on carrot may indicate some viable alternatives—sequential vs. systematic field sampling plans and evaluation of root galling rather than (or in addition to) nematode population densities (5,6). Many producers also recognize that nematicide use can result in increased economic returns, even in the absence of nematode population densities large enough to cause economically significant damage (14). Many tobacco nematicides also possess insecticidal properties. Some, such as carbofuran, fenamiphos, and oxamyl have limited systemic activity. The degree to which these products are used as nematicides vs. soil insecticides is unknown. However, many growers use these products because they possess a spectrum of activity against a number of pests, including root-knot nematode. Accordingly, another challenge in managing nematodes is development of nematicide thresholds that include more specific action criteria for a wider range of soil organisms and (or) pests.

In summary, management of root-knot nematodes on flue-cured tobacco in the southeastern United States has depended on crop rotation, destruction of crop debris as soon as possible after final harvest, host resistance, and use of nematicides. Future management of these pests will continue to be founded upon economically acceptable crop rotation systems and early destruction of tobacco roots and stalks. Continued research is needed to develop effective management strategies for mixed populations of root-knot nematodes, to incorporate resistance to the full range of *Meloidogyne* species and races that occur on tobacco into agronomically acceptable flue-cured tobacco cultivars, and to develop nematode advisory programs that will allow producers to optimize all management practices from an economical and ecological point of view.

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