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Impact of Cotton Production Systems on Management of *Hoplolaimus columbus*[1]

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Abstract: The effectiveness of selected cultural practices in managing the Columbia lance nematode, *Hoplolaimus columbus,* on cotton was evaluated in experiments in growers' infested fields. The effects of planting date, cotton cultivar, treatment with the growth regulator mepiquat chloride, and destruction of cotton-root systems after harvest on cotton-lint yield and population densities of *H. columbus* were studied. The yield of cotton cultivar Deltapine 50 was negatively related ($P = 0.054$) to initial population density of *H. columbus* whereas the yield of Deltapine 90 was not affected by preplant density of this nematode, indicating tolerance in Deltapine 90. Reproduction of this nematode did not differ on the two cultivars. Planting date and treatment with the growth regulator mepiquat chloride did not influence cotton yield in a consistent manner. Application of mepiquat chloride suppressed ($P \leqslant 0.05$) numbers of Columbia lance nematode, although there was an interaction ($P \leqslant 0.05$) with cultivar and year. Early vs. late destruction of cotton-root systems did not impact population densities of this nematode either year, and had no impact on the subsequent cotton crop. The nematicide fenamiphos increased ($P \leqslant 0.03$) cotton yield when *H. columbus* numbers exceeded the damage threshold.

Key words: Columbia lance nematode, cotton, crop loss, cropping system, cultural practices, *Gossypium hirsutum, Hoplolaimus columbus,* host-plant tolerance, management, nematode, planting date.

The Columbia lance nematode, *Hoplolaimus columbus* Sher, is limited in distribution to Georgia, North Carolina, South Carolina, and Alabama in the United States (Koenning et al., 1999). In areas where this pathogen occurs it can parasitize cotton, *Gossypium hirsutum* L.; corn, *Zea mays* L.; and soybean, *Glycine max* L., especially in sandy soils (Kinloch, 1998; Lewis and Smith, 1976; Noe, 1993; Nyczepir and Lewis, 1979; Perez et al., 1996; Schmitt and Bailey, 1990).

Nematode management in cotton is largely dependent on nematicides (Starr, 1998). Nematicides are effective in preventing cotton-yield suppression by *H. columbus* (Mueller and Sullivan, 1988; Noe, 1990; Schmitt and Bailey, 1990). The use of nematicides, however, is increasingly under scrutiny by public and government agencies. Furthermore, there is a need to produce crops more efficiently to compete in the world market. Tactics for management of Columbia lance nematode are limited. Rotation is not generally an option in fields infested with *H. columbus* due to its wide host range (Fassuliotis, 1974). Peanut and tobacco can be used in rotation with host crops, but hectarage of these crops is limited. Winter wheat or rye cover crops had no impact on population densities of *H. columbus* (Davis et al., 2000). Subsoiling in soils with a hardpan has increased cotton and soybean yield when *H. columbus* is present, but many farmers have adopted reduced tillage practices that may eliminate subsoiling (Hussey, 1977; Schmitt and Bailey, 1990). Resistance to *H. columbus* in cotton and soybean has not been found, although some cultivars are relatively tolerant to this nematode (Bowman and Schmitt, 1994; Hill et al., 1994; Mueller et al., 1988; Schmitt and Imbriani, 1987). The rapid expansion in numbers of cotton cultivars because of the deployment of transgenic insect- and herbicide-resistant traits has resulted in the use of cultivars with limited field data on nematode tolerance and(or) resistance.

Additional tactics for management of *H. columbus* are needed. Late planting of soybean is an effective means of alleviating soybean-yield suppression due to parasitism by the lesion nematode *Pratylenchus brachyurus* and the soybean cyst nematode *Heterodera glycines* (Koenning et al. 1985; Koenning et al., 1993). Planting date, however, had little impact on soybean yield in a field infested with *H. columbus* in South Carolina (Perez et al., 1996).

Field research conducted in 1994 and 1995 focused on the effects of cultural practices and cotton-production systems on the Columbia lance nematode and cotton-lint yield in the presence of this nematode. Specific objectives of this research were to evaluate the impact of planting date, cultivar earliness, growth regulator application, and early root destruction on population densities of *H. columbus,* and cotton-lint yield in the immediate and years subsequent to treatment.

Materials and Methods

Field experiments were conducted from 1994 through 1996 near Laurinburg, North Carolina, in a field that had been planted with cotton for at least 10 years. The soil type was a Marlborough sandy loam (clayey, kaolinitic, thermictypic, paleudult; 72% sand, 22% silt, 6% clay, <1% organic matter). Mean pre-plant population densities of *H. columbus* in the field sites

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were 431 ± 260, 384 ± 277 per 500 cm^3 soil in 1994 and 1995, respectively. The experimental design was a 2 × 2 × 2 × 2 factorial with two planting dates (early planting: 25 April 1994 and 18 April 1995; late planting: 13 May 1994 and 16 May 1995), two cultivars (Deltapine 50 [early] and Deltapine 90 [late]), treated or not treated with the growth regulator mepiquat chloride (Pix, BASF AG, Research Triangle Park, NC), and crop destruction by discing immediately after harvest vs. allowing the crop to be killed by frost and then discing. There were six replications for each treatment combination. Mepiquat chloride was applied at early bloom at 0.025 liter a.i./ha to selected plots. The root-destruction treatments were organized as split plots. All plots received an in-furrow application of aldicarb (Temik 15G, Aventis Crop Science Inc., Research Triangle Park, NC) at 0.5 kg a.i./ha for early-season insect control. Plots were four rows 15.3 m long with 1.01-m-row spacing and 3.0-m alleys.

To evaluate the impact of planting date, cultivar maturity, growth regulator application, and early crop destruction on subsequent crops, the plots were marked and planted again the following year. In the year immediately following the factorial experiment (1995 and 1996) all plots were planted with the cultivar Deltapine 90 in two row plots (split-split-plot design) and treated with either fenamiphos (Nemacur 15G Bayer, Kansas City, MO) at 2.4 kg a.i./ha in a 35-cm band or untreated. All plots received aldicarb in-furrow at 0.5 kg a.i./ha for insect control. The planting dates for the second year of the experiment were 18 April 1995 and 7 May 1996.

Cotton-lint yield was determined after picking with a modified commercial cotton picker from sub-samples of seed cotton. Samples for nematode assays for each plot were collected prior to planting and at 4- to 6-week intervals thereafter in the planting date study, and at pre-plant, midseason, and cotton harvest in the subsequent year of the experiment. Each soil sample consisted of 8 to 10 soil cores (2.5-cm-diam.) taken to a depth of 15 cm from the center two rows of each plot and composited. A 500-cm^3 sub-sample was processed by elutriation and centrifugation to extract adults and juveniles from soil. Roots were collected from a sieve on the elutriator and placed in a mist extractor for 5 days to collect vermiform stages (Barker et al., 1986).

Data analysis consisted of analysis of variance (ANOVA) for a split-plot and split-split-plot design, repeated measures ANOVA, and regression, including tests for heterogeneity of slopes using PC/SAS software (SAS Institute, Cary, NC). Analysis of covariance using preplant population densities of Columbia lance nematode as a covariate was used to generate least-squares means and standard errors for analysis of harvest population densities at the end of the first study year. Years for the field tests were considered to be random effects for combined analysis over years.

Results

Planting date, cultivar, and growth regulator impacts in the first year: Cotton-lint yield was lower ($P \leqslant 0.01$) in 1995 compared to 1994 for all treatments (Fig. 1). Early planting in 1994 was superior to late planting, but had no effect on cotton yield in 1995 (planting date × year, $P = 0.003$). Cultivar Deltapine 90 tended to yield more than Deltapine 50, but the influence of cultivar on yield was not significant ($P \leqslant 0.10$). The lack of difference was due to the significant first and second-order interactions of cultivar × year ($P = 0.0673$) and planting × cultivar × year ($P = 0.0106$). Regression analysis, however, demonstrated a negative relationship of preplant *H. columbus* population density on yield of Deltapine 50 ($P = 0.054$, $R^2 = 0.40$; data not included) but not on Deltapine 90 yield. The heterogeneity of slopes tests, however, indicated that the slopes did not differ ($P <$ 0.10). The application of the growth regulator mepiquat chloride had no impact on cotton-lint yield either year.

End-of-season population densities of *H. columbus* did not differ between 1994 and 1995 (Fig. 2). Neither cultivar nor planting date had an impact on nematode numbers either year. Treatment with the growth regulator at early bloom suppressed population densitities of *H. columbus* on Deltapine 50, especially in 1995, but not on Deltapine 90 (Fig. 2). There was a first-order interaction between growth regulator and cultivar ($P =$ 0.052) and a second-order interaction among cultivar, year, and growth regulator ($P = 0.014$).

Impact of treatments in the subsequent year and nematicide treatment: Population densities of *H. columbus* were greater ($P < 0.01$) in 1995 than in 1996 (Figs. 2,3). Survival rates were approximately 80% vs. 20% for the winters of 1994–1995 and 1995–1996, respectively. None of the previous years' cultural practices (planting date, cultivar, growth regulator treatment, or early destruction of cotton plants) affected pre-plant *H. colum-*

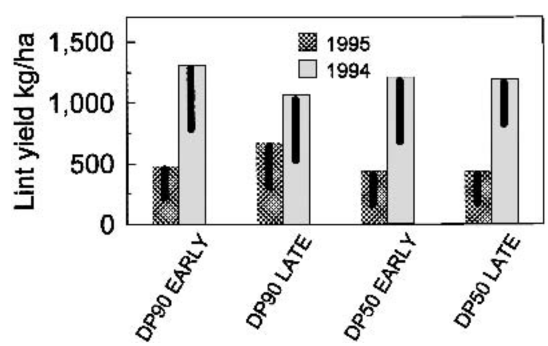

Fig. 1. Cotton-lint yield in 1994 and 1995 for two cotton cultivars (Deltapine 90 [DP90] and Deltapine 50 [DP50]), planted at two dates (early [April] or late [May]) in the presence of *Hoplolaimus columbus*. Yield differed between years ($P = 0.01$), cultivar × year ($P =$ 0.07), planting × year ($P = 0.0034$), and year × cultivar × planting ($P = 0.01$). Lines within bars are standard deviations of the mean. Application of the growth regulator mepiquat chloride did not affect yield. Each bar is based on 24 observations.

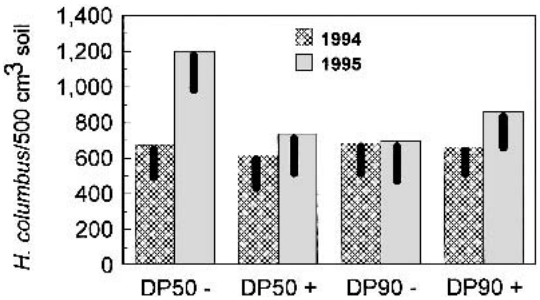

FIG. 2. Effects of cultivars (Deltapine 90 [DP90] and Deltapine 50 [DP50]), planted at two dates (early [April] or late [May]), year, and application of the growth regulator (treated with mepiquat chloride at early bloom at 0.025 liter a.i./ha [+] or nontreated [−]) on at-harvest population densities of *Hoplolaimus columbus* per 500 cm^3 soil in 1994 and 1995. Means are least-squares means adjusted for preplant population density, and lines within bars are standard errors. Mepiquat chloride suppressed population densities of *H. columbus* on Deltapine 50 ($P \leqslant 0.05$). A cultivar × year × growth regulator interaction was observed ($P = 0.01$). Each mean is based on 24 observations.

bus population densities in the spring 1995 and 1996 ($P < 0.10$). Interactions involving the previous years' growth regulator treatments were the only significant effects (data not included) other than the difference between years. Similarly, mid-season and harvest population densities of *H. columbus* were not influenced by previous years' treatments. Nematicide treatment, however, suppressed nematode numbers at these sampling dates in 1995, but not in 1996 (year × nematicide interaction; $P = 0.07$). The numbers of *H. columbus* increased from planting through mid-season and declined somewhat by harvest in 1995, but not in 1996. The population changes from planting to mid-season and cotton harvest in 1995 were adequately described by a quadratic model ($P < 0.01$, repeated measures ANOVA).

Cotton-lint yields in 1995 were lower ($P < 0.01$) than in 1996 (Fig. 4). The cotton yield in the subsequent year was not generally affected by the previous years' treatments (cultivar, planting date, or early destruction of cotton root systems), with one exception. The growth regulator treatment the previous year tended to enhance lint yield the second year in 1995 but not in 1996, as indicated by a growth regulator × year interaction ($P = 0.007$) (Fig. 4). Similarly, treatment with the nematicide phenamiphos had a positive impact ($P < 0.03$) on yield in 1995, but not in 1996, that also was reflected in a significant nematicide × year interaction ($P = 0.01$).

DISCUSSION

Planting date, cultivar, and growth regulator impacts in first-year experiments: Lower cotton yield in 1995 compared to 1994 was largely the result of variation in the amount and timing of rainfall between years. The rationale for evaluating the impact of planting dates was the assumption that *H. columbus* would cause less damage in early than in late plantings because this nematode has a high-temperature optimum for reproduction (Nyzcepir and Lewis, 1979). Early planting resulted in higher yields compared to late planting only with Deltapine 90 in 1994; the converse was true in 1995. Variation in cotton yield due to planting between 15 April and 15 May was generally a result of timing of rainfall during critical periods in cotton development. Typically, yield is much reduced with plantings after 15 May, and earlier planting is limited by the chance of a late frost in North Carolina (Anonymous, 2002). Yield of the less-tolerant Deltapine 50 was unaffected by planting date, whereas yield of tolerant Deltapine 90 was. The current research suggests that early planting

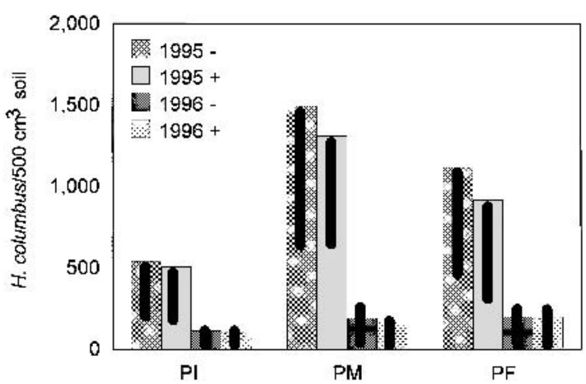

FIG. 3. Influence of year (1995 and 1996) and nematicide treatment (treated with fenamiphos 2.4 kg a.i./ha in a 35-cm band [+] or nontreated [−]) on *Hoplolaimus columbus* per 500 cm^3 soil preplant (Pi), mid-season (Pm), and harvest (Pf). Years were different ($P = 0.01$), as was the year × nematicide treatment interaction ($P = 0.01$). The previous years' treatments of planting date, cultivar, growth regulator treatment (mepiquat chloride applied at early bloom at 0.025 liter a.i./ha), and early destruction of cotton root systems had no effect on nematode population densities. Each bar is the mean of 96 observations. Lines within bars are standard deviations of the mean.

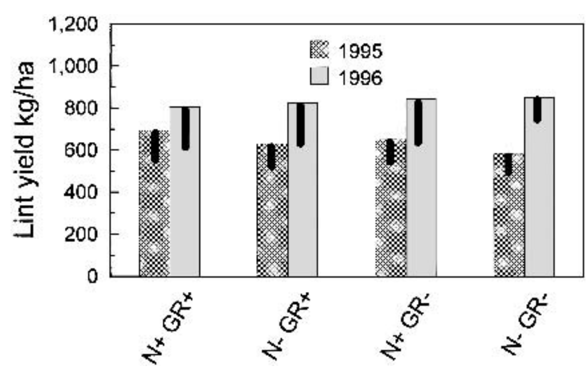

FIG. 4. Nematicide (fenamiphos 2.4 kg a.i./ha in a 35-cm band [+] or untreated [−]), the previous years' growth regulator treatment (mepiquat chloride applied at early bloom at the rate of 0.25 liter a.i./ha [+/−]), and year (1995–1996) effects on cotton-lint yield in a field infested with *Hoplolaimus columbus*. Years were different ($P < 0.01$), treatment with nematicide differed from nontreated ($P = 0.03$), the nematicide × year interaction was significant ($P < 0.01$), as was the effect of the growth regulator × year interaction ($P < 0.01$). Each bar is the mean of 48 observations, and lines within bars are the standard deviation of the mean.

date is probably not a viable option for avoidance of damage to cotton caused by Columbia lance nematode. Other research with this nematode exhibited no consistent impact of planting date on soybean yield, and nematicide treatment of late planted soybean resulted in significant yield increases (Mueller and Sanders, 1987; Perez et al., 1996).

Deltapine 90 was reported to be intolerant in South Carolina (Hill et al., 1994) but tolerant in North Carolina and Georgia (Bowman, pers. comm.; Nendick and Noe, 1994). Differences between cultivars in the current research are difficult to evaluate because of the interactions with year and planting date, but regression analysis (heterogeneity of slopes test) did not support the hypothesis that Deltapine 90 is more tolerant than Deltapine 50. The heterogeneity of slopes statistical test however, is limited because a positive response to increasing initial population density is not to be expected. An additional confounding factor is that cultivar Deltapine 90 is less determinant in its growth habit and matures later than Deltapine 50, which makes Deltapine 90 more tolerant of drought than Deltapine 50. A less-determinant (later maturity) cultivar is generally recommended for droughty soils in North Carolina (Anonymous, 2002). Because *H. columbus* generally occurs in sandy to loamy sands, the use of less-determinant cotton cultivars may be a good recommendation for growers where Columbia lance nematode is above the damage threshold.

Planting date had no effect on population densities of *H. columbus* at cotton harvest in the current research. This result agrees with similar work on soybean (Perez et al., 1996). No difference in reproduction of *H. columbus* was associated with the cotton cultivar used. Little difference in reproduction of *H. columbus* related to soybean or cotton cultivar has been noted, nor has tolerance been associated with reproduction of Columbia lance nematode (Mueller et al., 1988; Mueller and Sullivan, 1988; Nyzepir and Lewis, 1979).

No effect of early destruction of cotton root systems on *H. columbus* population densities was observed in our research either year, and there was no impact on cotton yield in the subsequent year. Nearly a month transpired before freezing temperatures, presumably adequate time for some increase in nematode numbers. Similarly, early destruction of cotton-root systems had an impact on population densities of Columbia lance nematode 1 year in Georgia, but not in a second year, and no effect on the yield of the subsequent crop either year (Davis et al., 2000). Soil temperatures are likely to drop below the relatively high temperatures required for this nematode to remain active in the late fall in North Carolina most years. The effects of application of the growth regulator mepiquat chloride on end-of-season numbers of *H. columbus* are difficult to interpret due to the first- and second-order interactions. The application of mepiquat chloride in growth chamber studies resulted in changes in partitioning of cotton biomass, with an increase in the mass of fine roots (Fernandez et al., 1991). The ability of various portions of the root system to support *H. columbus* reproduction is not known. Nonetheless, researchers should be aware that application of plant-growth regulators might affect nematode reproduction. The application of mepiquat chloride in experiments evaluating resistance to reniform or root-knot nematodes could affect interpretation of results.

Impact of treatments in the subsequent year and nematicide treatment: Yearly variation in survival of *H. columbus* between the winters of 1994–1995 and 1995–1996 has important implications for nematode advisory services. Typically, damage functions are based on fall samples for nematode assays and must assume that survival is relatively constant from year to year. This assumption may not be valid for Columbia lance nematode in North Carolina. North Carolina is currently the northern limit in distribution of this nematode (Koenning et al., 1999). Yearly variation in the survival of *H. columbus* at higher latitudes should be anticipated because of the high-temperature optimum for this nematode. Winter survival, as well as the requirement for relatively high temperatures for activity of this nematode, may be equally important in determining its distribution.

The low overwinter survival of *H. columbus* in 1995–1996 resulted in numbers of this nematode below the damage threshold in the majority of plots, higher cotton-lint yield, and no apparent impact of nematicide treatment on yield in 1996. The low nematode population densities in spring 1996 resulted in the year × nematicide interaction for lint yield. Suppression of *H. columbus* population densities by nematicide application should have had minimal impact on cotton-lint yield because the nematode numbers were below the damage threshold in 1996 (Anonymous, 2002). The lack of effect of the previous years' treatments on *H. columbus* numbers also was evident in cotton-lint yields, where the previous years' treatments generally had no impact with the exception of mepiquat chloride treatment the previous year. The significant decrease in cotton-lint yield in 1995 associated with no treatment of Deltapine 50 with mepiquat chloride correlated with high nematode numbers associated with this treatment at harvest in 1994.

The lack of suppression of *H. columbus* by fenamiphos in 1996 compared to 1995 is likely a result of the low Pi in 1996. Furthermore, fenamiphos was generally less effective than aldicarb in suppressing numbers of this nematode on cotton (Mueller and Sullivan, 1988; Schmitt and Bailey, 1990).

Options for management of Columbia lance nematode on cotton are limited, especially in areas where cotton production is intensive. The current research establishes that cotton production systems (early vs. late) have little impact on *H. columbus* population densities and did not alleviate the nematodes' impact on cotton yield in North Carolina. The ineffectiveness of cultural practices, including the lack of suitable rotation crops, for management of this nematode means that growers must rely on nematicides and(or) cultivars with high levels of tolerance. More emphasis on the development of and nature of tolerance to *H. columbus* in cotton are needed to alleviate yield suppression by this nematode.

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