THE EFFECTS OF RIDGE HEIGHT AND PLANT SPACING ON THE INTERACTION BETWEEN MELOIDOGYNE ARENARIA AND TOBACCO[1]

by Howard Ferris[2]

Interaction of **Meloidogyne arenaria** with tobacco grown at different stress levels, imposed by plant spacing and ridge height, was studied. Early in the season population densities of eggs and larvae were greatest at close spacing and in low ridges. Later, as interplant competition increased, nematode densities were greatest on the most vigorous plants, those at the widest spacing on high ridges. Averaged across ridge heights, tobacco yield per unit area was greatest at 51 cm spacing, least at 76 cm and intermediate at 25 cm. Yield per plant was lowest at the close spacing and greatest at the wide spacing. Yields were slightly greater with high ridges than with low ridges. Sampling error in nematode density determinations caused marked inflation of the variance estimates.

Key words: Plant spacing, ridge height, root knot, tobacco.

NEMATODE-INFECTED PLANTS suffer stress corresponding to the amount of root dysfunction. The effects of the stress may be ameliorated by environmental conditions favorable to plant growth or accentuated by unfavorable conditions. Environmental conditions can often be manipulated by the cultural practices employed. Thus, tobacco yields are affected by plant spacing (1, 4, 7) and by ridge height (6, 13). These variables directly or indirectly affect interplant competition for available resources. Plant vigor, in turn, affects host status as determined by the nematode reproduction rate, the equilibrium density of the population, or both (11).

Interactions between infection by *Meloidogyne arenaria* (Neal) Chitwood, tobacco plant spacing and ridge height were studied in the field in 1970. The magnitude and importance of sampling error in estimation of variance of the nematode population densities were determined at intervals throughout the growing season.

MATERIALS AND METHODS

The experimental site was located in Wake County, N.C., on a Norfolk sandy loam infested with *M. arenaria*. Recent tobacco crops in this field had been moderately damaged by root knot. The preplant nematode population density, as assessed by sugar-flotation-sieving (3), modified Baermann funnel (10) and greenhouse bioassay, was about 100 larvae per 500 cc soil.

A completely random design of 24 x 4-row plots incorporating two ridge heights and three plant spacings in a 2 x 3 factorial experiment was used. Each treatment was replicated four times. The rows were 1.1 m wide and 9.1 m long. The ridge heights were 15 and 30 cm above the original soil level, while the plants were set 25, 51 and 76 cm apart in the row. Except for the treatment variables, land preparation and cultural practices throughout the season were uniform across all plots and followed prescribed procedures (12). Tobacco transplants, c.v. 'Coker 319', were set with a handsetter on May 25.

Each plot was sampled for nematodes three times during the season (July 2, July 30 and Aug. 20). The *M. arenaria* population density was estimated by determining the number of eggs and second stage larvae. Sampling procedure was standardized to improve comparability of samples. A 25 cm sampling tube was inserted into the root zone about 15 cm from, and directed to about 30 cm below, the base of the stalk. In plots with less vigorous plants, a more acute angle of penetration was used to sample an equivalent region of the root zone. Two samples of 12 borings each were taken from each plot, one from each center row. On the two latter dates, similar sets of samples were also taken midway between plants.

Larval and egg fractions of the *M. arenaria* populations were measured by the procedures of Byrd *et al.* (3) and Byrd *et al.* (2), respectively. The tobacco was conventionally harvested and cured. Yields of cured leaf were recorded per plot and per plant in view of the different plant numbers under the spacing treatments. All root systems in the two center rows of each plot were pulled from the soil at the end of harvest, and root-knot indices were assessed (5).

RESULTS AND DISCUSSION

Root-zone densities of *M. arenaria* eggs plus larvae for three sampling dates are shown in **Table 1**. On July 2 there were significantly more nematodes ($P=0.03$) in plots with low ridges than in those with high ridges. Differences between spacings were not significant but LSD comparisons showed significantly fewer nematodes in the wide spacing x high ridge plots than in the close spacing x low ridge plots. On July 30 nematode density was again significantly higher in the low ridge plots ($P=0.04$). Apparently, as elsewhere (8, 9), a high ridge drawn from the upper layers of soil, is initially relatively free of nematodes. Population increase is delayed, allowing the plants to become established and to complete their early growth before being heavily infected. By the end of the season (Aug. 20), population densities under high and low ridges were about the same.

Plant spacing had little effect on the root-zone populations on July 2; by July 30 the population density under the 51-cm spacing was greatest and by Aug 20 density was linearly related to spacing, being greatest at the 76-cm spacing. At this stage of the season the greatest nematode density was in the high ridges and at wide spacing, being significantly greater than in the low ridges and at narrow spacing, the reverse of the early season densities.

M. arenaria densities midway between adjacent plants were determined on July 30 and Aug. 30 (**Table 2**). There was no significant difference with ridge height at either date. On July 30 the differences in nematode density with plant spacing were significant ($P=0.01$); the density was linearly related to spacing,

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being greatest at 25-cm. By the end of the season (Aug. 20), differences in nematode density with spacing were not significant.

Postharvest root-knot indices (5) did not differ significantly with ridge height (Table 3). Indices of plants at 51 and 76-cm spacings were significantly lower ($P=0.02$) than those at 25-cm. The root-knot index at the 76-cm spacing in the high ridge was significantly lower than those at the 25-cm spacing at either ridge height.

To account for the different plant numbers in the spacing treatments, yelds of cured tobacco leaf are presented on a per plot and per plant basis (**Table 4**). Yield per plot was not significantly affected by ridge height but it was significantly lower ($P=0.02$) at the 76-cm spacing than at 51 or 25-cm. The wide spacing at both ridge heights produced a significantly lower yield per plot than the close spacing in the high ridge. Yields per plant did not differ significantly with ridge height while the differences with plant spacing were significant ($P=0.01$). Yield per plant at the 25-cm spacing with both ridge heights was significantly lower than with any other treatment combination.

TABLE 1. Root-zone densities of M. arenaria on three dates in tobacco grown at three spacings and two ridge heights. 1970.

Ridge height (cm)	Spacing (cm)	(Eggs + larvae) (10^3)/500 cc soil July 2	July 30	Aug 20
30	25	47.6	112.4	169.3
(High)	51	49.7	91.0	191.5
	76	34.9	78.3	312.9
15	25	91.8	101.4	140.8
(Low)	51	53.3	221.6	267.3
	76	80.6	116.5	269.0
LSD .05		47.9	85.2	157.2
Main effects				
30		44.1	93.9	224.6
15		75.2	146.5	225.7
LSD .05		27.7	49.2	90.7
	25	69.7	106.9	155.0
	51	51.5	156.3	229.4
	76	57.7	97.4	290.9
	LSD .05	33.9	60.3	111.1

TABLE 2. Between-plant densities of M. arenaria on two dates in tobacco grown at three spacings and two ridge heights. 1970.

Ridge height (cm)	Spacing (cm)	(Eggs + larvae) (10^3)/500 cc soil July 30	Aug 20
30	25	52.4	31.4
(High)	51	12.6	41.3
	76	4.8	15.6
15	25	48.4	25.4
(Low)	51	31.0	26.2
	76	7.4	21.7
LSD .05		13.3	20.3
Main effects			
30		23.3	29.4
15		28.9	24.4
LSD .05		7.7	11.7
	25	50.4	28.4
	51	21.8	33.7
	76	6.1	18.6
	LSD .05	9.4	14.4

TABLE 3. Root-knot indices of tobacco grown at three spacings and two ridge heights in M. arenaria infested soil. 1970.

Ridge height (cm)	Spacing (cm)	Root-knot index[a]
30	25	93.0
(High)	51	89.2
	76	85.8
15	25	93.5
(Low)	51	88.4
	76	90.5
LSD .05		5.5
Main effects		
30		89.3
15		90.8
LSD .05		3.2
	25	93.3
	51	88.8
	76	88.1
	LSD .05	3.9

[a] *On a scale of 0-100 where 100 is maximum galling. Index of Daulton and Nusbaum, 1961.*

TABLE 4. Yield of tobacco grown at three spacings and two ridge heights in M. arenaria infested soil. 1970.

Ridge height (cm)	Spacing (cm)	Cured leaf—g Per plot	Per plant
30	25	1,690	49
(High)	51	1,660	94
	76	1,180	99
15	25	1,370	39
(Low)	51	1,540	85
	76	1,060	88
LSD .05		500	28
Main effects			
30		1,510	81
15		1,320	71
LSD .05		290	16
	25	1,530	44
	51	1,600	90
	76	1,120	93
	LSD .05	360	20

TABLE 5. Sampling error as a percentage of experimental error in samples of M. arenaria populations from tobacco plots.

Sampling date	Position	Percentage	Probability of > F[a]
July 2	Root zone	39.6	0.02
July 30	Root zone	109.7	0.57
July 30	Between	96.1	0.46
Aug 20	Root zone	60.0	0.12
Aug 20	Between	49.9	0.06

[a] *Under H_o of equality of experimental and sampling error.*

Yields per plant reflect that the intermediate and wide-spaced plants were the largest and most vigorous, thus capable of supporting the greatest nematode density by the end of the season. The highest population density on Aug. 20 was at the 76-cm spacing on high ridges. This treatment combination produced more tobacco per plant than the other treatments, indicating a more vigorous growth.

Treatment combinations with greatest nematode densities early in the season (low ridge x close spacing) ended with the greatest root-knot damage. These plots also had the lowest yield per plant although competition between plants is confounded in these observations and the yield loss cannot be attributed solely to nematode damage. It appeared, however, that increasing stress resulted in lower yields of the individual plants, and in greatest damage inflicted by the nematodes, as reflected by root-knot indices. In the low ridge x close spacing treatment combination, final nematode population density was lowest.

Results of population density assessments midway between plants may be indicative of the efficiency of space utilization in the ridge by roots at the various plant spacings. Probably the ridge was filled with roots early in the season at the 25-cm spacing and hence root competition started earlier, while it was only at the end of the season that available space was used at the 51-cm spacing. In the 76-cm spacing the available root space was apparently never fully used, accounting for the lower nematode densities between plants at this spacing. The 76-cm spacing on a high ridge had the most soil volume available for root growth and hence in this treatment the nematode density between plants was lowest. Efficiency of space utilization is also reflected by yields per unit area, which were greatest on high ridges at the close and intermediate spacing.

The experimental error (within treatments) mean square, used for testing treatment differences in an analysis of variance, has a component due to sampling error. Reduction of sampling error would cause greater reduction in the experimental error mean square than in the treatment mean square, so increasing the precision of the analysis. **Table 5** shows sampling error expressed as a percentage of experimental error and the probability of a greater F value under the null hy-

pothesis of equality, based on a F-test between them. Sampling error was significantly smaller than experimental error (P=0.02) at the first sampling (July 2), but thereafter it was impossible to reject the null hypothesis that they were the same. The relatively low sampling error at the first root-zone sampling probably had little effect on the precision of difference detection between treatments. By July 30 experimental error was indistinguishable from sampling error, resulting in marked variance inflation. Uniformity of nematode distribution apparently increased by the end of the season when sampling error fell to 50-60% of the total experimental error.

Aggregation of *Meloidogyne* eggs into masses tends to inflate sampling error, increasing the difficulty of measuring differences in population densities. A difference of a few egg masses in two samples from the same plot can result in a difference of several thousand in the egg density estimate. Standardization of sampling technique, by attempting to take samples from equivalent areas of the root zone of each plant, helps alleviate this problem. However, thrusting the sampling tube into the soil at a fixed angle has an inherent danger of magnifying sample differences when plant roots are growing extremely vigorously or are very stunted. In these cases the samples would be from different parts of the root zone, increasing sampling error. An increase in the number of samples from each plot would improve the precision of nematode density estimates.

High yields of tobacco per unit area, despite the presence of nematodes, were obtained with the current system (12) of high ridges and a spacing of about 51-cm. Although wider spacing reduces competition and allows the plant to grow more vigorously despite the nematode presence, the increased growth per plant does not compensate for the reduction in the number of plants on an area basis, as found by Chaplin *et al.* (4) and Boyce (1). Optimization of growing conditions enhances the ability of the plants to withstand the stress of the nematode infection. Increased growth vigor under conditions of minimized stress improves the host status of the plant relative to the nematode population, hence final nematode densities are greater than on stressed plants.

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