Impact of Row Spacing and Planting Date on the Canopy Environment, Abundance of Lesser Cornstalk Borer and Other Arthropods, and Incidence of Aflatoxigenic Fungi in Peanuts

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ABSTRACT

Three row spacings and two planting dates for peanuts, *Arachis hypogaea* L., were examined in 1993 and 1994 to determine the influence of the canopy environment on lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller) (Lepidoptera: Pyralidae), other arthropods, and alflatoxigenic fungi. Climatically, 1993 and 1994 were disparate years. Decreasing row spacing increased relative leaf area and light interception by the canopy but, compared to difference between planting dates or years, had a relatively small impact on soil temperatures and relative humidity within the canopy. Late planting produced smaller plants, retarded canopy development, and reduced yield in both years, but especially in 1993 when it was hot and dry. The wide row spacing did not yield as well as twin and normal row spacings in either year. Lesser cornstalk borer damage and aflatoxin concentration were higher in the late planting than in the early planting of 1993, but were unaffected by row spacing. Fewer predatory arthropods were caught as row spacing decreased in both beat and pitfall samples, but planting date had variable effects. Prevailing climatic conditions and planting date appeared to be more important in influencing the canopy environment and pest densities than was row spacing.

Key Words: Aflatoxin, *Arachis hypogaea*, *Aspergillus*, *Elasmopalpus lignosellus*, plant management.

The seed of peanut, *Arachis hypogaea* L., matures underground and soil-borne pests are often more important than above-ground pests. Soil-borne pests of peanut include the lesser cornstalk borer (LCB), *Elasmopalpus lignosellus* (Zeller) (Lepidoptera: Pyralidae), and aflatoxigenic fungi, *Aspergillus flavus*-type fungi (Deuteromycetes). The larvae of LCB feed on all peanut plant parts, including the roots, pegs, and developing seed pods (Leuck, 1966), and can cause significant yield loss when abundant. Infection of peanut pods with *A. flavus* Link or *A. parasiticus* Spear may rot or contaminate peanut seed with highly carcinogenic aflatoxins (Diener *et al.*, 1982). The presence of aflatoxins in food products is a worldwide concern, and allowable tolerances for aflatoxin contamination in peanuts are as low as 5 ppb. Lesser cornstalk borer larvae increase fungal and aflatoxin contamination in peanut seed through feeding activities (Lynch and Wilson, 1991; Bowen and Mack, 1993).

Both LCB and aflatoxigenic fungi are unusual in that they can tolerate xeric conditions (Sanders *et al.*, 1985, 1993; Mack and Appel, 1986). Lesser cornstalk borers have high fecundity and their larvae develop quickly at high temperatures and low humidities (Mack and Backman, 1984; Mack *et al.*, 1987). At the same time, hot and dry conditions may reduce the abundance of natural enemies that would normally prevent outbreaks of LCB (Mack, 1992). Soil temperatures in excess of 30 C, particularly during the last 20 or more days before harvest, are optimal for preharvest aflatoxin contamination of peanut (Sanders *et al.*, 1984, 1985). Consequently, heavy infestations of LCB and aflatoxin contamination are associated with hot dry conditions, especially for peanuts grown in sandy soils (Smith and Barfield, 1982).

Irrigation is an effective management strategy for reducing activity of aflatoxigenic fungi and populations of LCB, but this option is not available to many growers. Granular insecticides can be used to prevent or control LCB infestations (Mack *et al.*, 1989; Bowen and Mack, 1993) and possibly reduce the threat of aflatoxin contamination in the seed. However, soil insecticide applications are expensive, have deleterious effects on beneficial arthropod populations (Mack, 1992), and may induce outbreaks of other pests. Fungicides are generally not effective at reducing aflatoxin contamination in peanuts (Pettit *et al.*, 1971).

Temperature and moisture are important climatic factors for all organisms. With the exception of irrigation, the amount of moisture, solar radiation, or temperatures affecting an agroecosystem cannot be manipulated once a crop has been planted. However, this does not mean that there is no way to manage a field environment to favor beneficial species or to antagonize pests. For example, tillage practices may affect soil moisture and light reflectance, and thus affect soil temperature. The plants themselves modify their environment through shading and depletion of soil moisture.

When the peanut canopy grows over the bare soil between rows, competition from weeds can be reduced (Buchanan and Hauser, 1980; Colvin *et al.*, 1985; Cardina *et al.*, 1987). Twin row planting is a modified narrow row system. Peanuts planted with narrow row spacings have been shown to have greater ground cover, leaf area indices, canopy light interception, and crop growth rates than those planted with conventional row spacing of 91 cm (Jaaffar and Gardner, 1988). Yields tend to increase, with little effect on market quality, as peanuts are planted closer together compared with conventional plant

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spacings (Cox and Reid, 1965; Norden and Lipscomb, 1974; Jaaffar and Gardner, 1988). In soybean [*Glycine max* (L.) Merrill], pest and predator densities are altered by differential row spacings and planting dates, with most insects often caught in the narrow row spacings (Buschman *et al.*, 1984; Ferguson *et al.*, 1984; Troxclair and Boethel, 1984). Thus, row spacing can affect the environment within peanut fields and may influence populations of pest and beneficial organisms.

A proactive management strategy is needed that could reduce infestations by LCB and aflatoxigenic fungi in peanut while maintaining, or even increasing, populations of natural enemies. Preferably, this strategy would minimize the use of pesticides. Since LCB and aflatoxigenic fungi are more abundant in xeric conditions, management tactics that counteract hot and dry conditions will reduce the likelihood of outbreaks of these pests. The objective of our study was to determine whether the environment within the peanut canopy could be managed, through row spacing and planting date, to mitigate conditions favorable to outbreaks of LCB and seed invasion by aflatoxigenic fungi.

Materials and Methods

Design. In 1993 and 1994, Florunner peanuts were planted in three row spacings at the Wiregrass Substation, Alabama Agric. Exp. Stn., in Henry County, AL. Two planting dates (11 and 31 May, both years) were arranged in randomized complete block designs with four replications of three row spacings. Each plot was 21.3 m long and 12.8 m wide. Row spacings were normal (91 cm), wide (137 cm), and twin (23 cm rows spaced alternately at 56 cm and 91 cm).

In all plots, one application of pendimethalin (Prowl® 3.3 EC, 2.0 lb ai/ha) was used for preplant control of weeds and postemergence hand weeding was performed as needed to maintain weed-free plots. No irrigation or insecticide applications were made either year, but six to eight applications of chlorothalonil (Bravo® 720, 2.75 lb ai/ha) were applied postemergence as recommended for control of fungal leaf diseases (Weeks *et al.*, 1993).

Weather and Canopy Environment. Daily rainfall and temperature maxima and minima were recorded at the experiment station office, approximately 0.5 km from the field site. In addition, various environmental parameters were monitored in test plots.

At two locations in each plot, soil temperatures were measured weekly throughout the season. A soil temperature probe (Bravo® electronic thermometers, Hanna Industries, Woonsocket, RI) was used to measure temperature at a depth of approximately 3 cm under the edge of the canopy as it grew outward. In twin row plots, the probe was placed between rows that were spaced by 56 cm. Soil temperature measurements were taken between 1300 and 1500 hr CST and on the same sides of the rows to reduce variability caused by shading.

A thermohygrometer (Model HI 8564, Hanna Industries) was used to measure ambient temperature and relative humidity. In each plot, one above-canopy (approximately 1 m above ground) and two below-canopy (approximately 4 cm above ground) readings were taken weekly. Below-canopy readings were taken under the edge of canopy as it grew outward, and in twin row plots, between rows that were spaced by 56 cm. Relative humidity was not measured when conditions were especially wet or windy because this greatly affected the precision and accuracy of the instrument.

Two measurements of leaf temperature and relative humidity within the canopy were usually taken in each plot at weekly intervals using an Infrared Ag Multimeter (model 510B, Everest Interscience Inc., Fullerton, CA), but additional samples were taken during times of extreme temperature and drought. Elevated leaf temperatures may be a symptom of plants stressed by heat and drought (Erickson and Ketring, 1985; Coulson *et al.*, 1988).

Plant Growth. Various plant growth and canopy development parameters were measured at weekly intervals during the growing season. The distance separating the canopies of adjacent peanut rows (i.e., canopy closure) and plant height were measured in two randomly selected locations in each plot. In twin row plots, the 56-cm rows were sampled. Two to eight plants per plot were returned to the laboratory each week from which the number of nodes, number of pods, and leaf area of individual plants were determined. Leaf area (cm^2) of individual plants was measured (LI-3100 Area Meter, Li-Cor Inc., Lincoln, NE) after counting and removing leaves from the plant.

Relative leaf area was estimated by taking one above-row measurement and four ground-level measurements with a LAI-2000 Plant Canopy Analyzer (LI-COR Inc.). Ground-level measurements were taken diagonally from row center to about two-thirds the distance to the adjacent row. Relative leaf area was measured in each plot at about 0900 hr CST using a 45 lens cap. Again, in twin row plots, samples were taken between rows that were spaced by 56 cm.

Two weekly measurements of canopy light interception also were taken per plot. The instrument (LI-191SA Line Quantum Sensor, LI-COR Inc.) measured the 2-sec average of photosynthetically active radiation ($\mu mol/sec/m^2$) along its 1 m length. Data consisted of the difference in an above-canopy and ground-level reading taken between 1200 and 1400 hr CST on days when the sky was clear or nearly clear. The sensor was placed on the ground, centered, and perpendicular to the row, and for twin row plots, centered on the row adjacent to the 56-cm row spacing.

Predator Abundance. Pitfall traps (Mack and Backman, 1990) and beat samples were used to estimate the abundance of common natural enemies. Two pitfall traps were placed within one of the central rows of each plot shortly after seedling emergence, and traps were monitored weekly to determine the abundance of ground-dwelling predators.

A beat sample of 3.6 m of row was taken weekly in each plot to determine the abundance of natural enemies on the foliage. The growth habits of peanut plants and different row spacings made traditional beat sheet samples difficult. So, rather than shaking arthropods from plants onto a cloth, we identified and counted the arthropods from one row of plants directly on the ground. Only one row was sampled in a twin row pair.

Lesser Cornstalk Borer Abundance and Pod Damage. Soil sieve samples (Mack and Backman, 1987) for LCB larvae were taken weekly in each plot when the soil was dry enough for sieving. Each sample consisted of three consecutive plants pulled in two locations from which the number of LCB larvae were counted, and larvae collected

from sieving the soil around the plants. Only the plants were checked (i.e., sieving was not done) on the several occasions when the soil was too wet to pass through the sieve.

On the day plots of each planting date were harvested for yield (below), the number of plants in 2 m of row were counted to determine stand density in each plot. The first five pairs of plants within this 2 m were then hand harvested to determine the total number of pods, the average weight of whole pods, and the number of pods with apparent injury from larvae of the LCB (i.e., scarification or feeding holes). Southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber (Coleoptera: Chrysomeldiae), and wireworms (species of Coleptera: Elateridae), also may damage pods in a fashion similar to LCB. However, we observed no rootworms and very low numbers of wireworms during sampling in either year. Feeding injury was not recorded in 1994 because LCB larvae were not prevalent and feeding damage was not evident.

Aspergillus flavus, *Aflatoxin and Yield.* Prior to harvest, the incidence of *A. flavus*-type fungi on 10 pods from randomly selected plants was determined in each plot every 2 wk after initiation of pegging. Plants sampled for LCB were returned to laboratory. Pods were removed from the plants, surface-sterilized in a 0.525% sodium hypochlorite solution for 1 min., then placed on cotton padding moistened with 20% NaCl solution (Bowen and Mack, 1993). Identification of *A. flavus* was based on conidial color after at least 3 d incubation in the dark at 30 C and 99% relative humidity. Data were recorded as the proportion of pods infected with aflatoxigenic fungi.

Early and late plantings were dug (plants inverted) on 5 and 21 Oct. 1993 and on 12 and 28 Sept. 1994. Yield was estimated by harvesting two (four in the twin rows) of the center rows in each replicate 3 to 7 d after the rows were dug.

In each plot, one subsample of 20 randomly selected pods from the harvest was shelled and assayed as described previously for aflatoxigenic fungi; another subsample was shelled and assayed for aflatoxin concentration. Aflatoxin assays were conducted on 1-g samples that were taken from a 25-g sample of homogenized seed from each replicate. Total aflatoxin levels were quantified using the Aflatest® (Vicam, Somerville, MA).

Analyses. Some data were analyzed as a randomized complete block (Proc GLM, SAS Institute, 1990). When main effects were found to be significant, least significant differences (LSD, $\alpha = 0.05$) were calculated to separate means. For incidence of *A. flavus*, the proportion of infected pods was weighted by the number of pods in each sample after an arcsin transformation of the square root of each proportion.

Other data (e.g., plant height, canopy width, leaf area, arthropod densities) were regressed with a quadratic equation on Julian date, with row spacing and Julian planting date as linear covariates (Proc RSREG, SAS Institute, 1990). The plant density ratio for each row spacing was used as the covariate values for row spacing (i.e., 4:3:2 for twin, normal, and wide replicates, respectively). The significance of row spacing and planting date variables was based on whether these covariates statistically contribute to the model. Each year was analyzed separately due to generally large differences between data. Differences between years were based on lack of overlap of the quadratic parameters (± SE) for the regression models.

Results

Weather and Environment. The weather in 1993 was hot and dry, whereas 1994 was unusually cool and wet. Ambient temperature averaged 25.4 C at the station office, with 25 d of maximum temperature exceeding 35 C and 37 cm of rainfall between 1 May and 30 Sept. 1993. Ambient temperature did not reach 35 C at any time during 1994, and averaged 24.1 C with 93 cm of rainfall throughout the growing season. During the last 3 wk before harvest, ambient temperatures averaged 24.8 and 22.5 C for early planted peanuts in 1993 and 1994, respectively. The average ambient temperatures during the 3 wk prior to harvest of the late planted peanuts (after inversion of early planted peanuts) was 19.8 C in both years.

Soil temperatures were higher in 1993 than in 1994 (Table 1). Season-long averages of soil temperature differed due to crop planting dates only in 1993, when late planted peanuts had higher soil temperatures than the early planting (34.2 ± 0.2 vs. 33.6 ± 0.2 C; F = 3.84; df = 1,670; P = 0.05). Soil temperatures were lower in twin rows (33.1 ± 0.4 C) than in the other row spacings. (34.1 ± 0.4 C in wide and 33.7 ± 0.4 C in normal row spacings) only for the early planting in 1993 (F = 12.3; df = 2,180; P < 0.01). Soil temperatures in wide, normal, and twin spacings were different from each other after 1 Aug. 1993 (32.9 ± 0.5, 32.1 ± 0.4, and 31.0 ± 0.4 C, respectively).

The season-long averages of ambient temperature and humidity were higher beneath the canopy (33.6 ± 0.1 C; 56.3 ± 0.8%) than above it (31.8 ± 0.1 C; 52.8 ± 0.7%) when both years and planting dates combined (t = 21.7, 16.6; n = 1008, 768; P < 0.01 for both, respectively). This response was similar in both years even though it was considerably hotter and drier in 1993 than in 1994 (Table 1). However, neither row spacing nor planting date significantly affected the ambient temperature or humidity.

In 1993, leaf temperatures were higher and there was less humidity within the canopy of late planted peanuts (33.5 ± 0.3 C, 43.8 ± 1.3%) than in early peanuts (32.2 ± 0.3 C, 51.3 ± 1.2%) (F = 8.9, 18.0; df = 1,286 and P < 0.01 for both, respectively). In 1994, season-long means of leaf temperature were not affected by planting date (31.0 ± 0.2 C for both combined) but, again, relative humidity

Table 1. Season-long averages of ambient temperature, relative humidity, and soil temperature for 1993 and 1994 when data from both planting dates were combined.

Season-long average[a]	1993	1994
Ambient temperature above canopy (C)	32.9 ± 0.1 a	30.4 ± 0.1 b
Ambient temperature below canopy (C)	34.7 ± 0.2 a	32.1 ± 0.2 b
Relative humidity above canopy (%)	48.5 ± 0.8 a	58.6 ± 1.0 b
Relative humidity below canopy (%)	52.1 ± 0.9 a	61.9 ± 1.4 b
Soil temperature (C)	32.6 ± 0.2 a	31.8 ± 0.2 b

[a]Means, within rows, not followed by the same letter are significantly different (P < 0.05, LSD comparisons).

within the canopy of the late planting was lower than in early planting (49.8 ± 0.7 vs. 55.2 ± 0.7%; F = 28.9; df = 1,236; P < 0.01). No differences in leaf temperature and relative humidity within the canopy were attributable to row spacing.

Plant Growth. Based on counts at the ends of both seasons, in-row plant spacing for a single, twin row was two-thirds (6.8 ± 0.2 plants/0.9 m) that of the normal and wide rows (10.1 ± 0.3 plants/0.9 m). The ratio of plant density (per unit area) for twin, normal, and wide replicates was calculated as 4:3:2. Quadratic models described the relationship (in each year) of each of the plant growth parameters (height, width between canopies of adjacent rows, number of leaves, number of nodes, leaf area per plant, relative leaf area, and light interception) to Julian Date (Table 2; Fig. 1). These models were calculated with plant density ratio and planting date as covariates. The planting date covariate was significant in each model except for numbers of leaves per plant in 1994 (Table 2). Row spacing was a significant covariate in 1993 for plant height, canopy width, and relative leaf area and, in 1994, for canopy width, number of nodes per plant, relative leaf area, and light interception.

In general, plants grew more quickly and taller in 1994 than in 1993 (Fig. 1). In the quadratic models for plant height, parameter estimates for row spacing (1993, only) and planting date covariates were significantly negative (Table 2). Thus, increasing plant density (by decreasing row spacing) and delaying planting caused a reduction in plant height.

As expected, the distance separating the canopies of adjacent rows (canopy closure) decreased as each season progressed (Fig. 1). In both years, earlier planting and increased plant density (by reduced row spacing) reduced the amount of bare soil (or distance) between canopies of adjacent rows (Table 2). Row spacing and planting date significantly affected relative leaf area. In both years, increasing plant density and earlier planting increased relative leaf area. Relative leaf area was consistently greater in 1994 than in 1993 (Fig. 1).

Table 2. Parameter estimates for quadratic models, with Julian planting date and row spacing as covariates, that predict the height, width between the canopies of adjacent rows of peanuts, the number of nodes, and the number of leaves, leaf area per plant, relative leaf area, and light interception from date for 1993 and 1994 in early and late planted peanuts in three row spacings.

	Parameters and statistics for independent variables [a]							
Year	$b_0 \pm SE$	$b_1 \pm SE$	$b_2 \pm SE$ ($\bullet 10^{-3}$)	$b_3 \pm SE$	$b_4 \pm SE$	F	df	R^2
Plant height (cm)								
1993	-137.7 ± 14.3	2.11 ± 0.14	-4.30 ± 0.40	-9.28 ± 1.5	-0.55 ± 0.03	263.2	4,85	0.93
1994	-250.3 ± 19.6	3.17 ± 0.18	-6.88 ± 0.43	-1.60 ± 1.8 ns	-0.51 ± 0.04	195.7	4,76	0.91
Width (cm) between canopies of adjacent rows								
1993	530.6 ± 45.6	-4.86 ± 0.44	9.78 ± 1.04	-77.6 ± 4.8	1.03 ± 0.10	208.2	4,85	0.91
1994	741.0 ± 68.7	-6.00 ± 0.64	12.93 ± 1.51	-117.8 ± 6.2	0.44 ± 0.13	144.4	4,76	0.88
Number leaves/plant								
1993	-336.2 ± 84.4	3.92 ± 0.70	-7.50 ± 1.80	-2.9 ± 6.4 ns	-0.73 ± 0.13	57.8	4,52	0.82
1994	-939.4 ± 198.7	9.46 ± 1.88	-20.59 ± 4.54	-6.0 ± 16.2 ns	-0.27 ± 0.35 ns	35.8	4,70	0.52
Number nodes/plant								
1993	-11.7 ± 10.5 ns	0.39 ± 0.10	-0.77 ± 0.22	-0.14 ± 0.79 ns	-0.16 ± 0.02	41.5	4,52	0.76
1994	-38.5 ± 4.7	0.56 ± 0.04	-0.95 ± 0.11	-0.82 ± 0.39	-0.15 ± 0.01	751.8	4,70	0.98
Leaf area (cm^2)/plant								
1993	-10456.0 ± 1465	126.2 ± 13.7	-262.8 ± 31.3	20.2 ± 110 ns	-25.9 ± 2.3	85.8	4,52	0.87
1994	-11834.0 ± 1878	127.5 ± 17.8	-274.2 ± 42.9	-219.0 ± 153 ns	-11.6 ± 3.3	43.3	4,70	0.71
Relative leaf area								
1993	-23.9 ± 11.0	0.29 ± 0.10	-0.62 ± 0.22	1.37 ± 0.30	-0.069 ± 0.006	44.8	4,211	0.46
1994	-24.1 ± 3.8	0.24 ± 0.03	-0.53 ± 0.08	1.47 ± 0.25	-0.012 ± 0.005	25.2	4,222	0.31
Light interception ($\mu mol/sec/m^2$)								
1993	-9574.0 ± 630	106.6 ± 6.0	-224.6 ± 13.9	29.6 ± 56.9 ns	-14.7 ± 1.2	228.7	4,592	0.61
1994	-10780.0 ± 879	115.0 ± 8.0	-258.3 ± 18.4	366.9 ± 68.4	-9.0 ± 1.4	74.0	4,496	0.37

[a]For quadratic equation $Y = b_0 + b_1 \bullet X + b_2 \bullet X^2 + b_3 \bullet Row + b_4 \bullet Pdate$, where X is Julian date, Row is plant density ratio (see text), and Pdate is the Julian planting date; P < 0.0001 for all models. ns = parameters that are not significant.

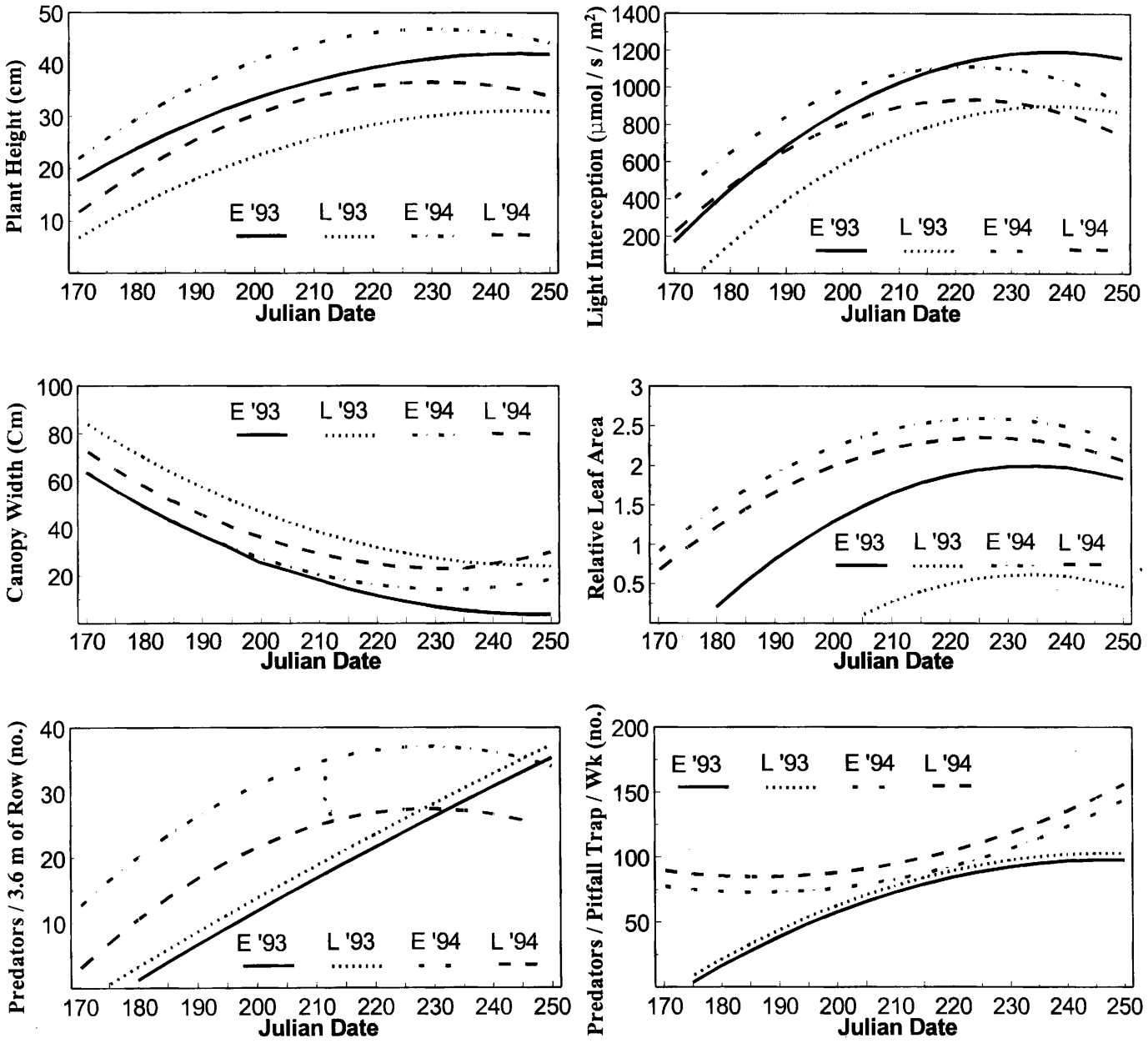

Fig. 1. Regression curves of plant height, width between the canopies of adjacent rows, relative leaf area, light interception and number of predators in beat and pitfall samples for early (E) and late (L) planted peanuts in 1993 and 1994. Only curves for the normal-row spacing are shown (see Table 2).

Plants from the 31 May planting had lower numbers of leaves and nodes, leaf area per plant, and light interception compared with those planted 11 May (Fig. 1). Row spacing had little measurable effect on these plant growth characteristics. However, the number of nodes per plant declined with more narrow row spacings (i.e., increasing plant density) in 1994, and decreasing row spacing significantly increased light interception by the canopy (Table 2).

Predator Abundance. The most abundant foliar predators were ants, primarily the imported red fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae). Season-long averages indicated that ants comprised 46% of the predators in beat samples in 1993 and 87% of the predators in 1994. Big-eyed bugs, *Geocoris* spp. (Hemiptera: Lygaeidae), constituted 38 and 3%, and various spiders (Araneae) comprised 8 and 6% of the predators in 1993 and 1994, respectively.

Ants constituted 20 and 60% of the ground-dwelling predators captured in pitfall traps in 1993 and 1994, respectively. Earwigs, primarily *Labidura riparia* (Pallus) (Dermaptera: Labiduridae), comprised 74% of the predators in pitfall traps in 1993 and only 34% in 1994.

The total number of predators in beat and pitfall samples was higher in 1994 than in 1993 (Fig. 1), primarily due to the increase in ant abundance. In 1993, planting date was not a significant covariate of predator abundance in either beat or pitfall samples (data not

shown). However, in 1994, the late planting had lower numbers of predators in beat samples but slightly greater numbers of predators in pitfall traps. Increased row spacing reduced the number of predators caught in beat samples (1993 only) and pitfall samples (both years).

Lesser Cornstalk Borer Abundance and Pod Damage. In 1993, more LCB larvae per plant were found in the late planting than in the early planting (0.63 ± 0.14 vs. 0.87 ± 0.11; F = 4.3; df = 1,203; P < 0.05). Most larvae (about 75%) were caught during late August and September. No differences attributable to row spacing were found in LCB abundance. The proportion of pods with injury apparently caused by LCB larvae was higher in late planted peanuts than in the early planting (62 vs. 35%; F = 31.9; df = 1,111; P < 0.0001), but row spacing did not affect pod injury.

In 1994, it was often too wet to effectively sieve the soil. Only a few LCB larvae were found at any time during the 1994 season when inspecting pulled plants (0.05 ± 0.02 per plant in the early planting and 0.02 ± 0.01 in the late planting). Consequently, there were too few larvae to determine if row spacing or planting date had an effect on LCB abundance in 1994.

Fungal Incidence and Aflatoxin. For pods collected prior to harvest, there was no difference between the incidence of *A. flavus*-type fungi in 1993 (12.5 ± 4.6%) and 1994 (18.2 ± 6.7%) when averaged over the two planting dates and three row spacings. However, in 1993, late planted peanuts did have a higher incidence of *A. flavus* than those planted 11 May (17.2 ± 8.3 vs. 8.4 ± 4.3%; t = 3.25, df = 131, P < 0.01). The incidence of *A. flavus* was unaffected by row spacing except for the late planting in 1994 when it was higher in pods from wide row plots than in plots with normal row spacing (Table 3).

For pods collected at harvest, there was no difference between the incidence of *A. flavus* when averaged over row spacings and planting dates in 1993 (27.7 ± 3.5%) compared with 1994 (20.9 ± 3.0%). However, late planted peanuts had a higher incidence of *A. flavus* than the early planting (t = 4.3, 2.0; df = 22,21; P ≤ 0.05 for 1993 and 1994, respectively). The incidence of *A. flavus* was unaffected by row spacing except for the late planting in 1994 when twin row plots had greater infection than other row spacings (Table 3).

In 1993, harvested seed from the late planting had more aflatoxin contamination than did early peanuts (64.1 ± 30.5 vs. 1.0 ± 0.1 ppb; F = 4.3; df = 1,23; P = 0.05). In 1994, late peanuts again had a numerically higher concentration of aflatoxin (199.6 ± 456.6 vs. 1.8 ± 0.7), but this difference was not significant (P > 0.20) due to the high variability of the data. Aflatoxin concentration in 1993 and 1994 was not affected by row spacing in either planting date (Table 3).

Yield. Yield, averaging 2784 kg/ha in 1994, was higher than in 1993 when yield was 592 kg/ha (F = 384; df = 1,47; P < 0.0001). Over 2 yr, peanuts planted 11 May yielded 1907 kg/ha, which was better than 1469 kg/ha from late planted peanuts (F = 14.8; df = 1,23; P < 0.001). In addition, row spacing affected yield in both plantings (Table 4). Yield from wide row plots was about one-third lower than in plots with other row spacings in both years.

Planting date and year had substantial effects on the average weight of individual pods that were hand harvested from pairs of plants at the end of each season (F = 41.7, 131.7; df = 1,190 and P < 0.0001 for both, respectively). Pods were 50-100% heavier in 1994 as compared with 1993 and, for both years, weighed more in the early than in the late planting (Table 4). For the late 1994 planting, pods from plots with twin row spacing weighed approximately 16% more than in the normal row spacing. The number of pods per plant also was affected by year, planting date (in 1993), and by row spacing (in 1994). For both planting dates combined, there were more than twice as many pods in 1994 than in 1993 (17.7 ± 0.8 vs. 7.7 ± 0.7; F = 22.0; df = 1,227; P < 0.0001). There were fewer pods per plant in the late planting than in the early planting for 1993 (3.5 ± 0.6 vs. 11.9 ± 0.9; F = 27.8; df = 1,96; P < 0.0001), but there was no difference between planting dates for 1994. In 1994, the number of pods harvested per plant in normal row spacings was less than in the other row spacings in the early and late plantings, respectively (Table 4; F = 3.4, 4.7; df = 2,54 and P < 0.05 for both).

Table 3. Mean incidence of *Aspergillus flavus* on preharvest pods and pods collected at harvest, and concentration of aflatoxin in harvested pods in early and late planted peanuts for three row spacings.[a]

Year	Spacing	Preharvest incidence ± SE		Incidence at harvest ± SE		Aflatoxin ± SE	
		Early	Late	Early	Late	Early	Late
		%		%		ppb	
1993	Twin	7.3 ± 6.4 a	20.7 ± 14.0 a	16.3 ± 7.2 a	42.5 ± 6.6 a	1.00 ± 0.00 a	19.30 ± 18.30 a
	Normal	8.5 ± 7.5 a	20.5 ± 17.8 a	13.8 ± 6.3 a	27.5 ± 6.3 a	0.75 ± 0.25 a	105.00 ± 83.20 a
	Wide	9.4 ± 8.4 a	10.3 ± 10.3 a	17.5 ± 3.2 a	48.8 ± 3.8 a	1.25 ± 0.25 a	68.00 ± 42.10 a
1994	Twin	22.5 ± 21.7 a	14.0 ± 14.8 ab	16.7 ± 1.7 a	46.3 ± 5.2 a	2.00 ± 0.00 a	594.00 ± 402.00 a
	Normal	17.0 ± 13.2 a	9.5 ± 8.4 a	13.8 ± 3.1 a	12.5 ± 6.0 b	2.00 ± 0.00 a	2.67 ± 0.67 a
	Wide	24.1 ± 17.8 a	22.5 ± 18.9 b	13.8 ± 3.1 a	21.3 ± 3.8 b	1.33 ± 0.67 a	2.00 ± 0.00 a

[a]Means, within columns and years, not followed by the same letter are significantly different (P < 0.05, LSD comparisons).

Table 4. Mean yield, number of pods per plant and weight of harvested pods in early and late planted peanuts for three row spacings.[a]

Year	Spacing	Yield ± SE		Pods/plant ± SE		Mean pod weight ± SE	
		Early	Late	Early	Late	Early	Late
		kg/0.4 ha		no.		g	
1993	Twin	370.1 ± 68.6 a	148.5 ± 23.5 a	13.4 ± 1.7 a	2.6 ± 0.5 a	0.65 ± 0.03 a	0.47 ± 0.06 a
	Normal	381.9 ± 107.7 a	162.6 ± 35.8 a	11.9 ± 1.7 a	3.0 ± 0.6 a	0.67 ± 0.05 a	0.48 ± 0.05 a
	Wide	264.0 ± 84.6 a	92.7 ± 44.7 a	10.6 ± 1.6 a	4.9 ± 1.7 a	0.60 ± 0.05 a	0.45 ± 0.05 a
1994	Twin	1311.0 ± 137.8 a	1260.0 ± 76.6 a	18.8 ± 2.2 a	19.1 ± 1.3 ab	0.98 ± 0.04 a	0.96 ± 0.03 a
	Normal	1412.0 ± 38.6 a	1101.0 ± 87.0 a	13.2 ± 1.6 b	14.1 ± 1.9 b	1.04 ± 0.04 a	0.83 ± 0.05 b
	Wide	837.6 ± 30.0 b	760.6 ± 50.7 b	19.1 ± 1.9 a	22.3 ± 2.5 a	0.98 ± 0.04 a	0.90 ± 0.02ab

[a]Means, within columns and years, not followed by the same letter are significantly different ($P < 0.05$, LSD comparisons).

Discussion

The greatest differences in our data for plant growth variables and insect densities were between years. The observation that peanut plants and insect densities responded differently from one year to the next can best be explained by the prevailing climatic differences. It was hotter and drier in 1993 than in 1994, and the lack of water at least partially explains why plants had less growth and lower yields in the first year of the study than in the second year (Williams and Boote, 1995). Drought conditions in 1993 also contributed to an increased occurrence of LCB larvae, lower predator numbers (Mack, 1992), and probably the higher concentration of aflatoxin in late planted peanuts. It has previously been reported that soil temperatures in excess of 30 C, particularly during the last 20 or more days before harvest, are optimum for preharvest aflatoxin contamination of peanut (Sanders *et al.*, 1984, 1985). However, alflatoxin contamination tended to be higher for the late plantings in our study despite the relatively cooler preharvest conditions when compared to the early planting.

Differences in the field environment between planting dates were detected in each of the 2 yr. Season-long averages of soil and leaf temperatures were lower in 1993 for peanuts planted 11 May compared with those planted later. In 1994, there were no measurable differences in soil and leaf temperatures between planting dates. Average relative humidity within the peanut canopy was higher in earlier planted peanuts than in the later planted peanuts in both years.

In both study years, earlier planted peanuts had greater plant height, more leaf area and nodes, increased light interception, and faster canopy closure compared with those planted 31 May. Because significant differences in soil or leaf temperatures due to planting date were only observed in 1993, these plant growth differences were more likely due to climatic conditions relative to plant developmental stage.

The inflated pod damage in the late planting of 1993 was at least partially caused by LCB larvae feeding on a lower number of pods than were available in the early planting. But in 1993, there were also fewer larvae found in peanuts planted 11 May compared with those planted 31 May. Substantially different rainfall was not observed on plants in one planting date versus the other in 1993. Thus, the cooler soil temperatures and increased humidity in earlier planted peanuts, compared with later planted peanuts, may have been enough to affect LCB populations.

The original premise was that increasing plant density, through decreased row spacing, would result in a cooler and more moist environment within and beneath the canopy of the developing peanut plants. In both years, decreasing row spacing did increase relative leaf area and canopy closure between adjacent rows. But only in early 1993 planting did we find a significant reduction of soil temperature associated with increased plant density in narrower row spacings. Row spacing had no consistent effects on relative humidity within the canopy, numbers of LCB larvae per plant, or the occurrence of aflatoxigenic fungi.

As in studies with soybean (Buschman *et al.*, 1984; Ferguson *et al.*, 1984; Troxclair and Boethel, 1984), we expected more predators to be found in narrow row peanuts. However, predators were more common in beat and pitfall samples of wider row spacings. Reduced predator numbers in narrow row plots may be an artifact of sampling different plant densities and row architectures. For example, predator densities in beat samples of twin row plots were equivalent or higher than in other row spacings on a per plant basis. The rows also may funnel predators into pitfall traps, and this funneling effect could be greater when the canopy does not close, such as in our wider row spacings. This seems plausible because most ground-dwelling arthropods are found in close association with the plants. The increased number of predators found in the cooler and wetter year may partially explain the decreased occurrence of LCB larva.

One concern, relative to the use of varying row spacings with differential plant densities, would be the yield of peanuts. Although plants in the wide row spacing produced equivalent or more pods per plant than in other spacings, yield was significantly lower due to lower plant density. Excessively wide row spacings or low plant densities have been shown to reduce yield in soybean and peanut (Ethredge *et al.*, 1989; Boquet, 1990; Wehtje *et al.*, 1992). Our normal and twin row peanuts had similar

yields even though plant densities were lower in the normal spacing. We also found that yield declined in the late planting of both years, dry (1993) and wet (1994), and this was primarily caused by a reduction in the number of pods produced per plant and a decrease in their weight.

It appears that row spacing in peanuts, within realistic confines, had only subtle effects on the canopy environment and pest populations in comparison with other factors such as planting date. Narrow row spacing may slightly reduce the likelihood of outbreaks by some pests. However, prevailing climatic conditions, in relation to plant phenology (as partly determined by planting date), were the most important factors. It seems likely that other managment practices, such as irrigation or insecticide applications, would be required when conditions are favorable for lesser cornstalk borer or aflatoxigenic fungi, regardless or row spacing.

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