Row Pattern, Plant Density, and Nitrogen Rate Effects on Corn Yield in the Southeastern US

Ronald B. Sorensen, Marshall C. Lamb, and Christopher L. Butts, Research Agronomist, Research Economist, and Agricultural Engineer, USDA-ARS-National Peanut Research Laboratory, PO Box 509, 1011 Forrester Dr. SE, Dawson, GA 39842

Corresponding author: Ronald B. Sorensen. rsorensen@nprl.usda.gov


Abstract
It is uncertain how corn (Zea mays L.) yield would be affected by planting in a twin-row orientation in the southeastern US. The objectives were to compare corn grain yield when: (i) planted in single and twin rows, (ii) plant densities at recommended (1R) and twice the recommended (2R) rate, and (iii) N rates of 168 and 336 kg/ha. Corn was irrigated using a subsurface drip irrigation system. The single and twin row with 1R seed density had the same corn grain yield (10069 kg/ha), stalk diameter (18.1 mm), and test weight (700 kg/m3). Twin-row 2R had lower grain yield (6967 kg/ha) and smaller stalk diameter (12.8 mm) compared with single- or twin-row 1R. Increased N did not affect grain yield or stalk diameter, but did increase grain test weight. Seed cost for the twin-row R2 was two times that of single- or twin-row R1. Seed cost percentage of gross revenue for single and twin R1 was 8% compared with 30% for twin-row R2.

Overall, this research implies corn can be planted in a twin-row pattern without loss of yield or gross revenue provided the plant population does not exceed the recommended rate.

Introduction
Corn (Zea mays L.) is an excellent rotational crop in the southeastern US for increased yield of peanut (Arachis hypogaea L). Sorensen et al. (14) showed that single-row peanut following corn averaged 12% higher pod yield than peanut following cotton (Gossypium hirsutum L.). From a peanut yield standpoint, the recommendation would be to plant corn in alternate years with peanut which would result in a 542-kg/ha pod yield increase compared with alternate year cotton. Research has also shown that planting peanut in twin vs single rows can increase pod yield by as much as 336 kg/ha and total sound mature kernels (TSMK) by one percent (2,3,4). In addition to yield and grade improvements, the twin-row orientation has shown reductions in incidence of Tomato spotted wilt virus (TSWV). Though the relationship between reduction of TSWV and planting in a twin-row pattern is not fully understood, this practice has become a standard recommendation (5,6).

Twin-row planting pattern would effectively spread plants farther apart both intra- and inter-row spacing allowing more distance between plants reducing plant competition for water, nutrients, and sunlight. Karlin and Camp (7) used twin rows centered on 0.93 m and 0.3 m with an average increase of yield of 0.64 Mg/ha with a plant population of 7.1 plants/ha. Other research (13) showed a grain yield increase with corn rows spaced at 0.45 m and plant population of 7.2 plants/m2.

Nitrogen is the nutrient that most often limits corn yield. Rhodes and Bennett (12) reviewed previous literature on corn nutrition seasonal uptake indicating that in the southeast (Florida) there was no increase of yield when N was applied over 220 kg/ha. This review (12) also concluded that a twin-row pattern consistently produced higher corn yields compared with a single-row pattern. Lamm et al. (9) showed that method of application had no influence on corn yield, however, the total amount of N applied did influence yield. Lamm et
al. (9) showed that N applied with subsurface drip irrigation (SDI) redistributed differently than surface applied N.

Southeast growers are advised to plant peanut using twin-row orientation for higher yield potential. This requires the purchase of a twin-row planter which is an added expense for the cost of the equipment. It would be cost effective to use a twin-row planter for other crops besides peanut. Assuming that a producer owns a twin-row planter for peanuts and that seeding rate for twin-row corn remains equal to single-row seeding rates, the only additional costs for twin-row planting would be repair and maintenance. Using repair and maintenance schedules derived from ASAE Standards (1), the twin-row planter had 3.5% higher per-hectare repair and maintenance costs compared with single-row planter. This equates to an estimated $0.52/ha/year. It is unknown how twin-row pattern, various plant densities, and N applied through an SDI system will affect corn grain yield. Therefore, the objectives of this research were to determine corn grain yield when: (i) planted in twin rows, (ii) plant densities were higher than recommended, and (iii) N was applied through a SDI system at recommended and twice the recommended rate.

Field Experiments

A subsurface drip irrigation system was installed in 2001 on a Greenville fine sandy clay loam soil (fine, kaolinitic, thermic Rhodic Kandiudults) located 1.6 km south of Shellman, GA. Thin-wall drip tubing (Typhoon 630, 15 mil, Netafim, USA) with emitters spaced at 0.46 m was installed 30 cm below the soil surface using a modified KMC chisel plow (Kelley Manufacturing Company, Tifton, GA). Drip tubing was spaced 0.91 m apart and had an emitter flow rate of 0.024 liter/min per emitter. Drip tubing was installed on 1.36 ha; this area was divided into 6 separate stations of 0.23 ha each. Each station was 45 m long and 49.3 m wide with 54 crop rows on 0.91 m spacing. Sub-plots, row pattern and plant density, were 5.46 m wide (6 rows) by 45 m long resulting in three treatments replicated three times within each station. There were a total of six SDI stations.

Two stations were used in 2003 and 2004. The crop rotation was such that corn was always planted following cotton. Treatments were arranged in a split plot, randomized block design with three replications per treatment. The main split (by station) was N with the row-pattern treatments randomized in each sub-block with three blocks within each station. Nitrogen was applied through the SDI system totaling 168 and 336 kg N per ha (N1 and N2, respectively). Plant pattern and density were single-row (S1) and twin-row (T1) planted at recommended plant density (11.2 plants/m2), and twin-row planted at twice (T2) the recommended rate.

Land preparation was started in late fall with mowing cotton stubble, pulling cotton stalks, disk harrowing, and reshaping the beds. Prior to planting, lime, phosphorus, and potassium were applied as recommended by soil test. Nitrogen was applied at 20 (2003) and 25 (2004) kg/ha as a pre-plant application. Both fertilizer and pre-plant herbicide (Eradicane 6.7 E; S-ethyl dipropylthiocarbamate at 5.8 liter/ha) were incorporated using a field cultivator.

Corn seed, cultivar DK697, was planted using a twin-row, double disk opener, vacuum planter at a seeding depth of 4.5 cm. Single-row orientation had crop rows spaced at 0.91 m and a plant density of 11.2 seeds/m2 (S1). Twin-row orientation had outside crop rows spaced at 0.91 m and inside crop rows spaced at 0.45 m with the twin-rows spaced 0.23 m apart. Seed density for the twin-row patterns were 11.2 seeds/m2 (T1) and 22.4 seeds/m2 (T2).

The SDI system was automated using an electronic datalogger (CR-23X, Campbell Scientific Inc., Logan, UT). The datalogger was also connected to an onsite weather station. The datalogger collected meteorological data and estimated potential evapotranspiration (ETp) using the Jensen-Haise equation modified for local conditions. Daily crop water use (ETa) was estimated by multiplying ETp by a crop coefficient (Kc) algorithm described by Lambert et al., (8). The datalogger calculated irrigation runtimes and controlled electronic...
solenoid valves for irrigation. An irrigation event was not applied if precipitation exceeded the estimated crop water use for that day. A maximum of 12.5 mm precipitation would be used as a "carry over" to stop irrigation for a short time span following a precipitation event. Daily ETa values were subtracted from the "carry over" until its value was zeroed, then irrigation events would resume. The 12.5 mm is about 25% soil moisture depletion for this soil type. After the first 30 days of plant growth, N was applied manually through the drip system at 25 and 50 kg N per ha increments for N1 and N2, respectively, at about 15-day intervals. All the N was applied prior to 90 days after planting.

Prior to harvest, final plant population was determined and stalk diameter was measured. The diameter was taken using vernier calipers between the second and third nodes. Corn grain was harvested using a four-row commercial corn combine. The total sample was weighed, recorded, and a 2.0-kg sub-sample was collected to determine moisture and test weight.

Yield data, test weight, and stalk diameter were analyzed using the general linear models ANOVA procedures described by Statistix8 (15) by year, N rate, row orientation, and seeding rate. ANOVA showed that yield data were significantly different by year; therefore, each year was analyzed separately. Mean separation between variables was obtained using Tukey's pairwise comparison procedure (P ≤ 0.05) when ANOVA showed significance.

**Yield and Economics**

Planting and harvest dates were similar for the two years (Table 1). Total water applied with both irrigation and rainfall was similar for both years. However, 2003 received 46% more rainfall requiring less irrigation amounts than 2004.

<table>
<thead>
<tr>
<th>Year</th>
<th>Plant date</th>
<th>Harvest date</th>
<th>Irrigation depth (mm)</th>
<th>Precip (mm)</th>
<th>Total water (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>26 Mar</td>
<td>20 Aug</td>
<td>76</td>
<td>659</td>
<td>735</td>
</tr>
<tr>
<td>2004</td>
<td>29 Mar</td>
<td>17 Aug</td>
<td>269</td>
<td>450</td>
<td>719</td>
</tr>
</tbody>
</table>

Grain yield was affected significantly by plant population in both 2003 and 2004. Treatment T2 had consistently lower grain yields compared with the S1 and T1 treatments during both crop years (Table 2). There was no difference in plant density, grain yield, test weight, or stalk diameter between S1 and T1. Widdicombe and Thelen (16) showed that grain yield increased as plant population increased when plant population ranged from 5.6 to 9.0 plants/m². Plant population in this study ranged from an average 8.5 to 18.06 plants/m². Other researchers have shown grain yield either increases or decreases at plant populations ranging from 8.6 to 10.1 plants/m² depending on location (12,13). At the recommended plant population, about 8.0 plants/m², treatments S1 and T1 averaged 10755 and 9384 kg/ha for 2003 and 2004, respectively. These grain yields are lower than those experienced by Widdicombe and Thelen (16).

Treatment T2 had the highest plant population and lowest stalk diameter compared with S1 and T1. Plant population was higher in T2 by design. With water and N being supplied through the drip system such that water or nutrient stress should have been minimized, it was hypothesized that the higher plant density would increase corn yield. Plant stalk diameter decreased probably due to higher plant competition (Table 2) for light and space as water and nutrients (N) should not have been limiting. Corn ears were smaller in the T2 treatment compared with S1 and T1 (corn ear size data not shown).

The smaller stalk diameter was on the average about 4.0 mm smaller in 2003 and 7.0 mm smaller in 2004 compared with S1 and T1. Smaller stalk diameter may increase the risk of stalk lodging. Widdicombe and Thelen (16) showed that as row width narrowed from 76 to 56 cm stalk lodging increased. There was no stalk lodging observed in either year of this research project.
Table 2. Relationship of plant treatments on plant density, grain yield, test weight, and stalk diameter for 2003 and 2004. S1 = single-row pattern planted at recommended rates; T1 = twin-row pattern planted at recommended rates; and T2 = twin row pattern planted at twice the recommended rate. Means followed by the same letter are not significantly different at the $P = 0.05$ level.

<table>
<thead>
<tr>
<th>Plant treatment</th>
<th>Plant density (plants/m²)</th>
<th>Grain yield (kg/ha)</th>
<th>Test weight (kg/m³)</th>
<th>Stalk diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>8.4a</td>
<td>10640a</td>
<td>704a</td>
<td>19.2a</td>
</tr>
<tr>
<td>T1</td>
<td>9.1a</td>
<td>10870a</td>
<td>695a</td>
<td>17.9a</td>
</tr>
<tr>
<td>T2</td>
<td>14.1b</td>
<td>9145b</td>
<td>697a</td>
<td>14.8b</td>
</tr>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>8.2a</td>
<td>9548a</td>
<td>702a</td>
<td>17.3a</td>
</tr>
<tr>
<td>T1</td>
<td>8.6a</td>
<td>9224a</td>
<td>705a</td>
<td>17.8a</td>
</tr>
<tr>
<td>T2</td>
<td>22.0b</td>
<td>4789b</td>
<td>701a</td>
<td>10.7b</td>
</tr>
</tbody>
</table>

Increased N rate did not increase corn grain yield or stalk diameter, but did significantly affect corn test weight in both 2003 and 2004 (Table 2). Lamm et al. (9) showed that corn grain yield did not increase when N rates increased from 280 to 420 kg/ha when supplied through a subsurface drip irrigation system. Corn grain averaged 10852 and 7852 kg/ha for 2003 and 2004, respectively. Lamm et al. (9), in western Kansas, showed much higher grain yield averaging 14700 kg/ha when irrigated at estimated water use and N rates similar to those used in this study.

Corn test weights were not significantly different between plant row and population treatments, but were different for the two N rates. Test weight increased an average of 9.4 kg/m³ with increased N rate. The higher N rate had an average test weight of 705 kg/m³ while the lower N rate had an average test weight of 695 kg/m³. In 2003, the test weight for the higher N treatment was 11% higher compared with the lower N treatment. In 2004, the test weight increased 8% as N rate doubled. Overall, added N increased test weight by 9.5%.

Seed cost for T2 was more than double the cost for S1 and T1 (Table 3). Gross revenue for S1 and T1 were essentially the same while T2 was substantially lower. The percentage of seed cost per gross revenue for S1 and T1 averaged 8% while this same ratio for T2 was about 30%.

Table 3. Relationship of plant treatments on gross revenue, seed cost, partial net return, and percentage of gross revenue needed to pay seed cost averaged for 2003 and 2004. S1 = single-row pattern planted at recommended rates; T1 = twin-row pattern planted at recommended rates; and T2 = twin row pattern planted at twice the recommended rate. Means followed by the same letter are not significantly different at the $P = 0.05$ level.

<table>
<thead>
<tr>
<th>Plant treatment</th>
<th>Gross revenue ($/ha)$^X$</th>
<th>Seed cost ($/ha)</th>
<th>Partial net return ($/ha)</th>
<th>Percent revenue as seed cost (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1076a</td>
<td>82.73a</td>
<td>993.27a</td>
<td>7.7a</td>
</tr>
<tr>
<td>T1</td>
<td>1077a</td>
<td>88.33a</td>
<td>988.97a</td>
<td>8.3a</td>
</tr>
<tr>
<td>T2</td>
<td>747b</td>
<td>180.64b</td>
<td>556.36b</td>
<td>29.4b</td>
</tr>
</tbody>
</table>

$^X$ Seed cost = $3.86/kg and market price = $0.11/kg.

**Corn Yield and Row Pattern Conclusions**

There was no difference in corn grain yield between single- and twin-row orientations provided the plant population was similar. However, when plant population was doubled such that each twin-row had the same population as the single-row population, this high rate of plant population resulted in lower
grain yield, smaller stalk diameter, and higher seed cost. Increased N did not affect grain yield or stalk diameter but did increase corn test weight. This research shows that corn planted in twin-row orientation has the same yield, stalk diameter, and test weight as corn planted in single-row orientation provided the plant density is similar. Increased N rates to compensate for high plant populations did not result with increased yield. Increased N did positively affect grain test weight. Overall, growers could use the same twin-row planter for corn as for peanut. This would save the grower from purchasing two planters, reducing equipment costs and associated expense and interest.

Acknowledgment

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Literature Cited