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EFFECT ON BOLL WEIGHT OF COTTON PLANTS PLANTED AT VARIOUS DENSITIES

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Abstract

Previous research has shown that yield of cotton increases with plant density until density reaches 16 to 20 plants m^{-2} . In 1997 and 1998 cotton was planted at various densities ranging from 2.5 to 22.5 plants m^{-2} in a RCB design. Ten row feet (3.048 m) of cotton were cut at ground level in each plot and placed into separate bags. Plant density for each plot was found by counting the number of plants in the bag representing that plot. For each plant, a boll found was placed in a small bag representing the fruiting branch and position from which it had been taken. A token was placed in the compartment which contained this bag. Any position without a harvestable boll was recorded as zero. Each small bag was weighed (total boll weight) and number of bolls were determined from the count of tokens thus providing mean boll weight. Mixed model analyses were performed on total yield, mean boll weight, and percent harvestable bolls; however, only mean boll weight will be presented. A response surface was determined for fruiting position by plant density.

1. Introduction

Cotton is an important crop in Georgia since almost 1.5 million acres were planted in 2001 producing 2.2 million bales (400 lbs) (Brown, 2002). This is about 8.4 % of the total cotton produced in the United States. Cotton plant growth and development is regulated by available resources such as sunlight, water, and nutrition (Bednarz et al., 1998; Kerby, 1996). Availability of these resources is affected by other organisms living in the same area such as weeds, insects, or other cotton plants. The objective of most population studies is to determine the plant density that will result in utilization of all available resources with a minimal amount of interplant competition. A population density of 35 to 50 thousand plants acre^{-1} (8.65 to 12.35 plants m^{-2}) in cotton is considered optimum. The sympodial fruiting branch (node) of cotton allows it to compensate for wide variations in stand density. Densities as low as 15 or as high as 60 thousand plants acre^{-1} (3.71 to 14.82 plants m^{-2}) may be acceptable. However, different population densities will change the amount of resources available to each individual plant, which will change the level of interplant competition and the manner in which the crop develops. Bridge et al. (1973), Jenkins et al. (1990), and Kerby (1996) stated that crowding cotton plants will initiate earliness even if the cultivar planted is considered early maturing.

Interestingly, few if any population studies have been conducted with production costs in mind (Bednarz et al., 1998). The U.S. Farm Bill, rising production costs, and increased foreign competition have compelled agronomists to investigate management practices that will help reduce production costs. One such management practice may lie in the area of seeding rates and population densities. If seeding

rates were reduced by one seed foot⁻¹ of row, seed costs could be reduced by \$2.78 acre⁻¹ assuming \$45.00 bag⁻¹ and 4,700 seed lb⁻¹. Monsanto announced in 1998 technology fees will be placed on a bag of seed. Therefore a bag of BG/RR (BollgardTM gene/Roundup ReadyTM gene) cottonseed will cost \$238.50 bag⁻¹. If transgenic seeding rates were reduced by one seed foot⁻¹ of row, seed costs would be reduced by \$14.76 acre⁻¹ assuming 4,700 seed lb⁻¹. The purpose of this study was to determine the lowest possible seeding rate in cotton that will not result in significant reductions in lint yield or lint quality and to investigate changes in growth and development of the crop under resulting population densities. Also, a secondary purpose was to find the seeding rate where seedcotton yield no longer is increasing.

1.1. Spatial Distribution of Bolls on the Cotton Plant

Jenkins et al. (1990) examined the distribution of cotton yield on eight cultivars (ST 213, ST 506, ST 825, CAMD-E, DPL 50 MC 235, DES 119, DPL 20) by node and position. Cotton was planted at 95 plants m⁻². A node refers to any sympodial fruiting branch on which a boll may occur. Lower nodes are usually called monopodium (vegetative) branches because they look like miniature main stems. Upper nodes are called sympodium (fruiting) branches where one or more bolls appear one at each fruiting site. Vegetative bolls may also appear where the sympodial branch connects to the main stem, or in rare cases, on the opposite side of the main stem. Cultivars varied from 51% (nodes 10-14) to 69% (nodes 8-14) to 75% (nodes 8-15) in total lint yield. The same three cultivars varied 73.5 % to 69.2 % to 72.5 % lint yield on first position bolls compared with total lint yields for the same nodes.

Kerby (1996) showed from data collected at numerous locations that 51 % of the bolls were in nodes 8-12 for the first position, 52.7 % were for all positions, and 66.3 % of all bolls in nodes 8-12 were first position bolls. Second position bolls occurred from node 5 through 20, while third position bolls occurred from node 6 through 16.

There have been at least nine published studies involving the effect of population density on the lint yield of cotton (Hawkins and Peacock, 1970; 1973; Fowler and Ray, 1997; Kerby et al., 1990; Jones and Wells, 1997; Hicks et al., 1989; Bridge et al., 1973; Smith et al. 1979; Culp et al., 1974).

Hawkins and Peacock (1970) conducted population density trials for three years. Densities ranged from 3.2 to 24.1 plants m⁻². Maximum lint yield occurred at 14.9 plants m⁻² in 1964, to 19.7 plants m⁻² in 1967, and 17.3 plants m⁻² in 1968.

Hawkins and Peacock (1973) conducted three population density trials in 1970 and 1971 at two densities (12.8 and 25.6 plants m⁻²) with four row widths (25.4, 50.8, 76.2, and 101.6 cm). They reported no difference between the two densities, but found an effect due to row width. However, viewing the means of trial, density, and row width would suggest that trial 2 was unusually erratic which would negate any row width effects. Boll weight showed no response to either density or row width. Estimated calculus values for density show that 16.24 plants m⁻² to be a minimum for lint yield, while 10.93 to be a maximum for boll weight.

Fowler and Ray (1997) conducted a population density trial on two cultivars, Paymaster 101A was early maturing and well adapted to western Texas, while C.A. 491 was selected because of its response to high density trials and earlier fruiting. Population densities examined ranged from 3.875 to 62.0 plants m⁻². Maximum lint yield using log₁₀ density occurred at 9.6 plants m⁻² for Paymaster 101A and 14.9 plants m⁻² for C.A. 491.

Kerby et al. (1990) conducted population density trials in 1984 and 1985 on five cultivars: 'Acala SJ-2' was most indeterminate and tallest, 'Acala SJC-1' and Shafter genotype 2218 were moderate determinacy and height, and Shafter genotypes 2280 and 2086 were least indeterminate and shortest. Population densities tested were 5, 10, and 15 plants m⁻². The calculus on density for lint yields were 9.2 plants m⁻² for 'Acala SJ-2' (max), 11.3 plants m⁻² for 'Acala SJC-1' (min), 14.9 plants m⁻² for Shafter

genotype 2218 (min), 18.7 plants m^{-2} for Shafter genotype 2280 (max), and 16.25 plants m^{-2} for Shafter genotype 2086 (max). The calculus on density for percent total bolls (mean of five cultivars) on nodes 9-12 was 9.6 plants m^{-2} (max), for percent total bolls on nodes 13-20 was 7.8 plants m^{-2} (min), and for percent total first position bolls on all nodes was 16.3 plants m^{-2} (max). As plant density increased from 5 to 10 plants m^{-2} there was a tendency for percent bolls to shift from nodes below number nine to nodes 9-12. When density increased from 10 to 15 plants m^{-2} there was a tendency for percent total bolls to shift from nodes below number thirteen to nodes 13-20. At both increases of plant density, percent total bolls shifted to the first position: 48.3-64.2% (on nodes 5-10) and 64.2-71.1% (on nodes 10-15).

Jones and Wells (1997) conducted population density trials for two years (1992, 1993) at two densities (2 and 12 plants m^{-2}). Numbers of mature bolls were greater at day 95 (1992) and at day 87 (1993) for the density of 12 plants m^{-2} , while cumulative number of mature bolls remained higher throughout the season for both years. At the lower density, number of mature bolls was spread out among the nodes 1-20 (1992) and nodes 1-15 (1993). At the higher density, number of mature bolls were concentrated among nodes 6-15 (1992) and nodes 6-10 (1993). This indicates that fruiting is concentrating among the center nodes. At the lower density the percent mature bolls at the first position were 23.4% (1992) and 21.0% (1993). At the higher density the percent mature bolls at the first position were 80.5% (1992) and 86.3% (1993). This indicates that fruiting is rapidly concentrating near the main stem.

Hicks et al. (1989) conducted population density trials in 1986 and 1987 with two cultivars ('Acala A246' and 'Paymaster 404'). The calculus on density lint yield was 10.7 plants m^{-2} (max) for 'Acala A246' in 1986 and 4.73 plants m^{-2} (max) in 1987; and 20.5 plants m^{-2} (max) for 'Paymaster 404' in 1986 and 5.35 plants m^{-2} (min) in 1987.

Bridge et al. (1973) conducted a three year study (1969-1971) involving two methods of planting the cotton: Hill where hills were 38 cm apart with either 1, 3, 5, 7, or 9 plants hill⁻¹ (2.46 to 18.65 plants m^{-2}); and Row where in-row spacing of plants were 38.0, 12.7, 7.6, 5.3, or 4.3 cm (2.71 to 22.41 plants m^{-2}). Maximum lint yields occurred at 13.35 plants m^{-2} for total and 13.81 plants m^{-2} for first-pick (FP) in 1969 for the Hill planting method; 7.09 plants m^{-2} for total and 8.17 plants m^{-2} for FP in 1970; and 11.16 plants m^{-2} for total and 11.16 plants m^{-2} for FP in 1971. Maximum lint yields occurred at 13.98 plants m^{-2} for total and 14.07 plants m^{-2} for first-pick (FP) in 1969 for the Row planting method; 11.40 plants m^{-2} for total and 12.02 plants m^{-2} for FP in 1970; and 12.64 plants m^{-2} for total and 13.27 plants m^{-2} for FP in 1971. The maximum yield calculus for density would have been overestimated had only the first-pick lint yields been evaluated which indicates that maturing early may be a consequence of excessive plant crowding.

Smith et al. (1979) conducted a population study involving two years (1975, 1976) and 3 cultivars ('Quapaw', 'Rex 713', 'DPL 16'). Population densities examined were 3.4, 10.2, and 17.0 plants m^{-2} . Maximum lint yield occurred at 11.31 plants m^{-2} .

Baker (1976) conducted a population density study involving three years (1971-1973) with two row patterns (two twin rows spaced at either 25.4 or 40.6 cm) and three population densities (21.5, 28.7, 35.8 plants m^{-2}). There was no difference in lint yield in response to either row pattern or density or when compared with the traditional two row planting (91.4 cm apart). Lint yield was increasing with the highest density in the ultra-narrow twin rows and had leveled off in the wider twin rows. The only reported response was the abundance of blooms on the highest density in the ultra-narrow twin rows, but bloom counts had declined at the highest density in the wider twin rows.

Culp et al. (1974) conducted two studies which examined the effect of population density on cotton lint production. The first study involved planting cotton in hills 35.6 cm apart and the rows were 101.6 cm apart. Four rows were planted per plot. The design consisted of a RCB with four treatments (2.77, 5.53, 8.30, 11.06 plants m^{-2}) and four replications. Lint yield (kg ha^{-1}) was maximized at 6.54 plants m^{-2} , while boll weight (g boll^{-1}) at less than 0 plants m^{-2} . The second study involved planting cotton

either in the conventional rows (101.6 cm apart, 4 rows bed⁻¹) or in twin rows (50.8 cm apart, 8 rows bed⁻¹), and spacing seed at a rate of 2 or 4 plants foot⁻¹. Lint yield (kg ha⁻¹) was minimized at 24.57 plants m⁻², while boll weight (g boll⁻¹) at 41.40 plants m⁻².

Wilson et al. (2002) presented the distribution of fruit (cotton boll) on five varieties with the genes for insect resistance (B) and herbicide resistance (RR). Even mean boll weight was erratic in the first three nodes and on nodes 13 and greater, in between (nodes 4-12) mean boll weight ranged between 4 and 5 grams boll⁻¹ depending on the variety. the greatest percentage of harvestable bolls occurred on nodes 9-13 which is where the greatest contribution to seedcotton yield occurred.

2. Methods and Materials

2.1. Experimental Design and Field Work

Seeding rate studies were conducted at the Coastal Plain Experiment Station (UGA-Tifton Campus) in Tifton, Georgia, USA (Bednarz et al., 2000). Cotton ('Suregrow 501') was planted April 25, 1997 at the main campus center pivot, May 9, 1997 at the Ponder Farm (9 miles west), and May 4, 1998 at the Ponder Farm. Five seeding rate treatments were established in a RCB with three replications at the center pivot using a Monosem air planter and consisted of 0.8 to 4.4 seeds foot⁻¹ of row on 36" rows (see Table 1). Four seeding rate treatments were established in a RCB with three replications at the Ponder Farm using a Monosem air planter and consisted of 0.7 to 6.4 seeds foot⁻¹ of row on 36" rows (see Table 2). Five seeding rate treatments were established in a RCB with four replications at the Ponder Farm using a Monosem air planter and consisted of 0.8 to 5.1 seeds foot⁻¹ of row on 36" rows (see Table 3). Management practices at both locations were consistent with those of high yielding production systems. All locations were irrigated when soil moisture potentiometers indicated need. Upon crop maturity, 10 row feet (3.048 m) from each plot were box picked (all plants are cut off at 2" above ground and placed in a bag labeled with plot id for later examination) for yield distribution determination. Later, each plant in each bag was examined for location of each boll where its node number and position number on node were recorded as was the weight of the boll (Jenkins et al., 1990; Bednarz and Roberts, 2000, 2001; Bednarz, 2002). From the recorded data, the following data variables were available: Seedcotton yield (kg ha⁻¹) for each node and position and total for the node, accumulated seedcotton yield (kg ha⁻¹), percent harvestable bolls, and mean boll weight (g boll⁻¹). Mean boll weight will be the only variable reported. The number of plants in each bag was also recorded. Density (plants m⁻²) was calculated from the number of plants in the bag.

Due to variability of individual cotton plants that were sampled from each plot, higher nodes (branches) with few bolls were added to the next lower branch in the same fruiting position so that the highest node number was somewhat consistent within a treatment. Some outer positions (i.e., position three bolls) when found to be sparsely represented were added to position two data on the same node.

2.2. Statistical Analysis of Data

All data were analyzed using Proc MIXED (Littell et al., 1996; SAS, 2000). The full model included as fixed effects: Density Treatment, Node, and Density x Node interaction; while the random effects included: Replication (Rep), Rep x Density (Error a), Rep x Node (Error b), and Rep x Density x Node (Error c, called residual error in Proc MIXED).

The response surface model included as fixed effects: Density linear and quadratic, node linear,

quadratic, and cubic, and density linear interacting with node linear and quadratic. Population density was centered on 9.836 (see Draper and Smith, 1981) using observed density - mean density ($D - \bar{D}$). Node was centered on 7 which is believed to be the peak producing node (Kerby, 1996; Jenkins et al., 1990) using observed node - peak node ($N - \text{peak } N$). Random effects include Error a, Error b, and Error c. Replication does not appear since it is confounded with individual plots. Each plot had its own population density due to planter and/or germination problems.

3. Results and Discussion

Preliminary analyses revealed that the three locations could not be analyzed together, especially for seedcotton yield (kg ha^{-1}) and accumulated seedcotton yield (kg ha^{-1}). The three fields are presented separately using the following notation: P97 = Ponder Farm 1997, R97 = RDC Center Pivot at main campus 1997, and P98 = Ponder Farm 1998. Unless otherwise noted the data are also presented as total of all positions (sum of positions 1-3), position one (bolls found at the first fruiting position on a fruiting node [branch]), position two (bolls found at the second fruiting position on a node), and position three (bolls found at the remaining fruiting positions on a node). Summary of the data by field, density treatment, and fruiting node position is presented in Table 4. Note that the number of nodes with at least one cotton boll found was fairly consistent for positions one and two regardless of the population density. This is in contrast to the severe reduction experienced with position three boll production. At the highest density in P97-7, there were very few bolls found and these were incorporated into position two data resulting in the absence of any bolls which is believed to exist under normal field conditions. The N presented are numbers of producing nodes found among the replications. The only variable presented reflecting individual plants is mean boll weight.

3.1. Mean Boll Weight

The full model analysis results for mean boll weight are shown in Tables 5, 7, & 9. The bolls found in each bag were weighed, counted, and mean boll weight was calculated. The value was recalculated when it was determined that extremely sparse boll data should be merged with neighboring data. The only places where harvestable bolls were found constitutes this data, position three is especially vulnerable to problems with sparse data. The response surface analyses are shown in Tables 6, 8, & 10. Regression coefficients from the response surface analyses are shown in Table 11.

Analysis results (full model) for mean boll weight from P97 appear in Table 5. Evident is the effect of population density being greater for every position data parameter compared with node. Both were significant for every parameter except for position three. Interaction between density and node was not significant for every position parameter, but position three had the largest effect. Random effect of error c was largest for positions one and two, somewhat smaller for total of all positions, and smaller yet for position three. Error b random effect was positive for all four position data parameters with larger values for positions two and three. Error a random effect was positive for every position data parameter except for position three which fell victim due to sparseness of the data.

Analysis results (response surface) from P97 for mean boll weight appear in Table 6. Node quadratic and node linear were the largest significant fixed effects for total of all positions followed by density linear, density linear by node linear, and density linear by node quadratic, while node cubic was excluded ($F < 1$). Node quadratic and node linear were the largest significant effects for position one followed by density linear, density linear by node quadratic, density linear by node linear, and density quadratic, while node cubic was excluded ($F < 1$). Density linear was the largest significant effect for position two followed by node linear and node quadratic, while both interactions were excluded ($F < 1$).

Node linear was the only significant effect for position three even though node quadratic was nearly as large, but node cubic and both interactions were excluded ($F < 1$). Random effects for errors a, b, and c were positive for total of all positions, and positions one and two. Random effects for errors a and c were positive and the only effects estimable for position three ($N=43$).

Analysis results (full model) for mean boll weight from R97 appear in Table 7. The erratic relationship between the effects of population density and node is evident. For total of all positions, although both F-values were similar only node was significant due primarily to error degrees of freedom. For position one, density was larger but both were significant. For position two, both were small resulting in node being significant and density was not. For position three, density was significant while node was extremely small and not significant. Interaction between density and node was significant for only position three. The random effect for error c was largest for positions one and two. Error b random effect was positive for all four position data parameters. Error a random effect was positive every position parameter except for position three (least data).

Analysis results (response surface) from R97 for mean boll weight appear in Table 8. Node quadratic and node linear were the only significant fixed effects for total of all positions, while node cubic was excluded from the model ($F < 1$). Node quadratic, density linear, node linear, and density quadratic were the only significant effects for position one, while all other effects were excluded ($F < 1$). Node quadratic was the only significant effect for position two while density quadratic, node cubic, and both interactions were excluded ($F < 1$). Density linear and density linear by node linear were the only significant effects, while node quadratic and cubic, and the second interaction were excluded ($F < 1$). Random effects for errors a, b, and c were positive for total of all positions, and positions one and two. Random effect for error c was positive for position three ($N=105$).

Analysis results (full model) for mean boll weight from P98 appear in Table 9. Node effect was significant for total of all positions, and positions one and two. Population density effect was significant only for position two where it was greater than the node effect. Interaction between density and node was significant for all position data parameters except for position two. The random effect of error c increased from total of all positions through position three. Error b random effect was positive only for total of all positions and position three. Error a random effect was positive only for positions two and three.

Analysis results (response surface) from P98 for mean boll weight appear in Table 10. Node linear and quadratic, and both interactions were the only significant fixed effects for total of all positions and position two, while node cubic was excluded from the model ($F < 1$). Node linear and node quadratic were the only significant effects for position one, while density quadratic, node cubic, and density linear by node quadratic were excluded ($F < 1$). Density linear and both interactions were the only significant effects for position three, while density quadratic and node cubic were excluded ($F < 1$). Random effects for errors a, b, and c were positive for positions two and three ($N=168$). Random effects for errors b and c were positive for total of all positions, but only error c was positive for position one.

Figure 1 shows the graphical presentation of the effect of plant density and fruiting node on mean boll weight for P97. For total of all fruiting positions (Fig. 1a), mean boll weight increased towards fruiting nodes 10-11 where it peaked and gradually declined with increasing node to 21. There was a slight decline in mean boll weight as density increased towards 22.5. For the first fruiting position (Fig. 1b), mean boll weight increased more sharply towards fruiting nodes 9-11 where it peaked and declined sharply with increasing node to 21. There was a distinct decline as density increased towards 14.5 where the decline became less. For the second fruiting position (Fig. 1c), mean boll weight increased sharply towards fruiting nodes 8-9 where it peaked then declined more gradually to node 20. Boll weight declined more until node 14.5 where the decline became less. For the third fruiting position (Fig. 1d), mean boll weight increased towards fruiting nodes 8-9 where it peaked then declined to node 18. The decline in boll weight was sharp as density increased towards 9.5-11.5 where there was a slight increase in boll weight

towards 14.5. One notable feature was the regular decline in the number of nodes actually involved in producing bolls declining from 3-18 to 6-13.

Figure 2 shows the graphical presentation of the effect of plant density and fruiting node on mean boll weight for R97. The major difference between P97 and R97 was that the plant density reached only 15.5 for R97, whereas it reached 22.5 for P97. This one effect changed the relationship observed in the cotton that affected mean boll weight and where on the plant bolls were likely to be produced. For total of all positions (Fig. 2a), mean boll weight remained the same for the first 7 fruiting nodes (3-9) then began a gradual decline towards node 21. This was fairly consistent over the range of plant densities. For the first fruiting position (Fig. 2b), the shape of the response surface was nearly the same as for the total of all positions. For the second fruiting position (Fig. 2c), the shape of the response surface suggests a gradual decline in mean boll weight from node 3 through 20. For the third fruiting position (Fig. 11d), mean boll weight declined in all directions from node 3 at a density of 3.5 towards the higher nodes and/or densities.

Figure 3 shows the graphical presentation of the effect of plant density and fruiting node on mean boll weight for P98. A difference between R97 and P98 even though their plant densities did not exceed 15.5 and 18 respectively was the crop of cotton was more distributed across the nodes and positions in P98 than in R97 even though total yield was higher for R97. For total of all positions and the first position (Figs. 3a,b), the shape of the response surface compared with R97 showed a slight increase in boll weight towards node 10 with P98. For the second position (Fig. 3c), the response surface has a distinct arch to it at the lower densities and a twisting trending towards the highest density and node 3. For the third position (Fig. 3d), there was a definite decline in boll weights as the nodes increased even at the lower densities. But as density increased, the higher nodes became less involved then quit producing bolls until only nodes 3-11 were producing bolls.

4. Summary

Given that the literature tended to support the notion that fruiting node seven tended to be the greatest in terms of yield production on the cotton plant, it was discovered that actually nodes 7-12 is the region of greatest impact on yield. Some evidence suggested that this region increased to 7-14 or 8-14 when moderate crowding occurred, but the region 7-12 returned to be greatest when crowding became excessive. Definitely, position three quickly gave up production capabilities when crowding began to be excessive and eventually was excluded for all practical intent at densities exceeding 18 plants m^{-2} . Position two picked up the slack until crowding became so excessive that it too gave up production capability. At the highest densities, it was position one that actually made the crop yield occur. The fact that mean boll weight remained above five grams boll⁻¹ and percent harvestable bolls (data not shown) declined so sharply played a major role in total yield remaining high despite the fact that plant densities were reaching beyond the excessive level.

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Table 1. Actual Plant Density and Range of Nodes by Plant and Position for Each Field Plot from the Ponder Farm 9 miles West of Tifton, GA in 1997.

Density (no m ⁻²)	Rep	All Positions		First Position		Second Position		Third Position	
		Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top
2.51	1	3	21	3	21	3	18	3	18
2.87	2	3	21	3	21	3	20	3	17
3.95	3	3	20	3	20	3	17	3	15
3.11	Mean	3	20	3	20	3	18	3	16
10.04	1	3	21	3	21	3	19	4	9
11.12	2	3	19	3	19	3	16	4	13
10.40	3	3	19	3	19	3	18	5	9
10.52	Mean	3	20	3	20	3	17	5	10
13.27	1	3	20	3	20	4	16	6	13
12.19	2	4	20	4	20	4	16	8	12
12.91	3	3	18	3	18	3	14	6	10
12.79	Mean	3	19	3	19	4	15	6	11
20.80	1	3	20	3	20	5	16	-	-
21.88	2	4	19	4	19	6	15	-	-
22.95	3	3	16	3	16	5	16	-	-
21.88	Mean	3	18	3	18	6	15	-	-
Mean		3	19	3	19	4	16	4	12

Table 2. Actual Plant Density and Range of Nodes by Plant and Position for Each Field Plot from the Center Pivot on the CPES Tifton Campus, GA in 1997.

Density (no m ⁻²)	Rep	All Positions		First Position		Second Position		Third Position	
		Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top
5.02	1	3	20	3	20	3	19	3	16
2.87	2	3	21	3	21	3	20	3	14
3.23	3	3	21	3	21	3	18	4	16
3.71	Mean	3	20	3	20	3	19	4	15
5.02	1	3	21	3	21	3	20	3	14
5.38	2	3	21	3	21	3	18	3	16
5.38	3	3	21	3	21	3	20	3	17
5.26	Mean	3	21	3	21	3	19	3	15
8.97	1	3	21	3	21	3	18	4	17
9.32	2	3	21	3	21	3	18	3	16
12.55	3	3	20	3	20	3	19	5	18
10.28	Mean	3	20	3	20	3	18	4	17
13.63	1	3	21	3	21	3	19	6	17
12.91	2	3	19	3	19	3	15	5	12
11.84	3	3	21	3	21	3	21	3	19
12.79	Mean	3	20	3	20	3	18	4	16
13.99	1	3	20	3	20	3	20	6	14
15.78	2	3	19	3	19	3	16	6	14
15.78	3	3	20	3	20	3	19	7	15
15.18	Mean	3	19	3	19	3	18	7	14
Mean		3	20	3	20	3	18	5	16

Table 3. Actual Plant Density and Range of Nodes by Plant and Position for Each Field Plot from the Ponder Farm 9 miles West of Tifton, GA in 1998.

Density (no m ⁻²)	Rep	All Positions		First Position		Second Position		Third Position	
		Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top
3.23	1	3	19	3	19	3	19	3	16
2.87	2	3	20	3	20	3	17	3	14
3.59	3	3	21	3	21	3	19	3	17
2.87	4	3	20	3	20	3	18	3	18
3.14	Mean	3	20	3	20	3	18	3	16
5.68	1	3	21	3	21	3	18	3	17
5.02	2	3	21	3	21	3	19	3	17
6.10	3	3	19	3	19	3	16	3	15
6.10	4	3	17	3	17	3	17	3	15
5.65	Mean	3	19	3	19	3	17	3	16
7.89	1	3	19	3	19	3	16	3	14
7.89	2	3	17	3	17	3	15	3	14
7.89	3	3	19	3	19	4	17	3	15
8.97	4	3	18	3	18	3	16	3	16
8.16	Mean	3	18	3	18	4	16	3	14
11.48	1	3	18	3	18	3	18	3	16
10.04	2	3	19	3	19	3	15	3	14
10.76	3	3	19	3	19	3	16	3	13
10.40	4	3	17	3	17	3	15	3	14
10.67	Mean	3	18	3	18	3	16	3	14
15.06	1	3	18	3	18	3	16	3	14
18.29	2	3	17	3	17	3	17	3	17
14.35	3	3	19	3	19	3	14	3	10
17.57	4	3	17	3	17	3	15	3	11
16.32	Mean	3	17	3	17	3	15	3	13
Mean		3	18	3	18	3	16	3	15

Table 4. Mean planting density, and number nodes and node range by treatment for three fields for each of three node positions for 1997 and 1998 in Tifton.

Field-Treatment	Population Density ² (no m ⁻²)	Position One		Position Two		Position Three ¹	
		N	Node Range	N	Node Range	N	Node Range
P97-1 ³	3.11(0.62)	56	3-21	49	3-20	44	3-18
P97-3	10.52(0.48)	53	3-21	47	3-19	21	4-13
P97-4	12.79(0.47)	51	3-20	38	3-16	18	6-13
P97-7	21.88(0.90)	48	3-20	34	5-16	0	---
R97-1	3.71(0.95)	56	3-21	48	3-19	40	3-16
R97-2	5.26(0.20)	57	3-21	52	3-20	41	3-17
R97-3	10.28(1.62)	56	3-21	49	3-19	42	3-18
R97-4	12.79(0.78)	55	3-21	49	3-21	37	3-19
R97-5	15.18(0.87)	53	3-20	48	3-20	27	6-15
P98-1	3.14(0.31)	72	3-21	65	3-19	57	3-18
P98-2	5.65(0.47)	70	3-21	62	3-19	56	3-17
P98-3	8.16(0.48)	65	3-19	55	3-17	51	3-16
P98-4	10.67(0.56)	65	3-19	56	3-18	49	3-16
P98-6	16.32(1.68)	62	3-18	54	3-17	44	3-17

Notes: 1: Position 3 would include any cotton bolls found further out on the node branch. 2: Standard deviation enclosed in parentheses, mean and SD are weighted to the number of producing nodes found having a cotton boll in position 1. 3: P97 = Ponder 1997, R97 = RDC Pivot 1997, and P98 = Ponder 1998. Treatments 1-7 represent number of cotton seeds planted per foot by settings on the Monosem air planter. Since the seed is small, two seeds being planted is not uncommon and hard to guard against. Plot thinning was done to try to achieve the desired population density for each plot.

Table 5. F-tests (fixed) and variance components (random) from full mixed model applied to mean boll weight (g boll^{-1}) for all positions, position one, two, and three grown at Ponder Farm 1997 in Tift County, Georgia.

Mixed Model Effects	Mean Boll Weight (g boll^{-1})							
	All Positions		Position One		Position Two		Position Three	
	df	Value	df	Value	df	Value	df	Value
Random	Variance Components							
Replication	2	0.0430	2	0.0454	2	0.0068	2	0
Error a	6	0.0377	6	0.0410	6	0.0967	1	0
Error b	29	0.1047	29	0.0551	22	0.3061+	18	0.5738
Error c	68	0.4710**	68	0.6639**	40	0.6758**	1	0.3218
Fixed	F tests							
Density	3	10.66**	3	16.18**	3	8.56*	2	16.13
Node	15	4.47**	15	5.50**	13	2.27*	11	0.95
Density x Node	42	1.10	42	1.10	27	1.47	6	5.16

Note: +, *, ** denote significance levels of $P=0.10, 0.05, 0.01$, respectively. N = 166, 166, 114, 42 for All Positions, Positions One, Two, and Three, respectively.

Table 6. F-tests (fixed) and variance components (random) from response surface mixed model applied to mean boll weight (g boll⁻¹) for all positions, position one, two, and three grown at Ponder Farm 1997 in Tift County, Georgia.

Mixed Model Effects	Mean Boll Weight (g boll ⁻¹)							
	All Positions		Position One		Position Two		Position Three	
	df	Value	df	Value	df	Value	df	Value
Random	Variance Components							
Error a	9	0.0707*	9	0.0590+	9	0.0804	3	0.6732*
Error b	42	0.1117*	42	0.1242*	32	0.4418+	-	-
Error c	108	0.4543**	108	0.6189**	67	0.8045**	34	0.9040**
Fixed	F tests							
Density Linear	1	6.86*	1	16.86**	1	18.24**	1	0.04
Density Quadratic	1	2.08	1	6.30*	1	2.63	1	0.65
Node Linear	1	39.39**	1	39.67**	1	14.83**	1	4.19*
Node Quadratic	1	54.65**	1	57.42**	1	6.60*	1	4.00+
Node Cubic	-	-	-	-	1	1.55	-	-
Density L x Node L	1	6.17*	1	9.89**	-	-	-	-
Density L x Node Q	1	5.32*	1	10.06**	-	-	-	-

Note: +, *, ** denote significance levels of $P=0.10, 0.05, 0.01$, respectively. N = 166, 166, 114, 42 for All Positions, Positions One, Two, and Three, respectively. Replication not included as a random since it is confound with fitting density in model.

Table 7. F-tests (fixed) and variance components (random) from full mixed model applied to mean boll weight (g boll^{-1}) for all positions, position one, two, and three grown at Main Campus RDC Pivot 1997 in Tift County, Georgia.

Mixed Model Effects	Mean Boll Weight (g boll^{-1})							
	All Positions		Position One		Position Two		Position Three	
	df	Value	df	Value	df	Value	df	Value
Random	Variance Components							
Replication	2	0.0121	2	0.0119	2	0	2	0.0071
Error a	8	0.0327	8	0.0115	8	0.1473+	8	0
Error b	32	0.0084	31	0.0624	26	0.0332	20	0.1799
Error c	112	0.4488**	111	0.6656**	78	0.7509**	23	0.5630**
Fixed	F tests							
Density	4	2.73	4	6.08*	4	1.00	4	5.97*
Node	17	2.76**	17	2.49*	16	1.95*	13	0.42
Density x Node	65	0.87	65	0.93	54	1.23	34	2.13*

Note: +, *, ** denote significance levels of $P=0.10, 0.05, 0.01$, respectively. N = 241, 240, 189, 105 for All Positions, Positions One, Two, and Three, respectively.

Table 8. F-tests (fixed) and variance components (random) from response surface mixed model applied to mean boll weight (g boll⁻¹) for all positions, position one, two, and three grown at Campus Pivot 1997 in Tift County, Georgia.

Mixed Model Effects	Mean Boll Weight (g boll ⁻¹)							
	All Positions		Position One		Position Two		Position Three	
	df	Value	df	Value	df	Value	df	Value
Random	Variance Components							
Error a	12	0.0223+	12	0.0016	13	0.0877*	12	0
Error b	47	0.0234	47	0.0482	40	0.0185	32	0
Error c	175	0.4135**	176	0.6427**	132	0.8310**	56	0.8363**
Fixed	F tests							
Density Linear	1	1.96	1	14.96**	1	2.16	1	15.80**
Density Quadratic	1	4.27+	1	4.84*	-	-	1	1.58
Node Linear	1	10.71**	1	7.67**	1	0.37	1	0.09
Node Quadratic	1	28.26**	1	25.67**	1	4.80*	-	-
Node Cubic	-	-	-	-	-	-	-	-
Density L x Node L	1	2.02	-	-	-	-	1	9.48**
Density L x Node Q	1	3.36+	-	-	-	-	-	-

Note: +, *, ** denote significance levels of $P=0.10, 0.05, 0.01$, respectively. N = 241, 240, 189, 105 for All Positions, Positions One, Two, and Three, respectively. Replication not included as a random since it is confound with fitting density in model.

Table 9. F-tests (fixed) and variance components (random) from full mixed model applied to mean boll weight (g boll^{-1}) for all positions, position one, two, and three grown at Ponder Farm 1998 in Tift County, Georgia.

Mixed Model Effects	Mean Boll Weight (g boll^{-1})							
	All Positions		Position One		Position Two		Position Three	
	df	Value	df	Value	df	Value	df	Value
Random	Variance Components							
Replication	3	0.0182	3	0.0014	3	0.0003	3	0.0110
Error a	12	0	12	0	12	0.0109	12	0.0803
Error b	42	0.0158	41	0	34	0	30	0.0115
Error c	134	0.3796**	129	0.6067**	101	0.6807**	70	0.8628**
Fixed	F tests							
Density	4	2.06	4	2.33	4	4.47*	4	0.83
Node	15	6.72**	15	5.67**	13	2.71**	11	1.66
Density x Node	53	1.48*	53	1.53*	44	1.37	37	1.61*

Note: +, *, ** denote significance levels of $P=0.10, 0.05, 0.01$, respectively. N = 264, 258, 212, 168 for All Positions, Positions One, Two, and Three, respectively.

Table 10. F-tests (fixed) and variance components (random) from response surface mixed model applied to mean boll weight (g boll⁻¹) for all positions, position one, two, and three grown at Ponder Farm 1998 in Tift County, Georgia.

Mixed Model Effects	Mean Boll Weight (g boll ⁻¹)							
	All Positions		Position One		Position Two		Position Three	
	df	Value	df	Value	df	Value	df	Value
Random	Variance Components							
Error a	17	0	18	0	17	0.0385	18	0.0273
Error b	55	0.0480+	54	0	45	0.0434	39	0.1542+
Error c	185	0.3948**	181	0.6923**	143	0.6628**	105	0.8613**
Fixed	F tests							
Density Linear	1	0.20	1	1.22	1	1.88	1	11.02**
Density Quadratic	1	0.85	-	-	1	1.93	-	-
Node Linear	1	38.24**	1	24.38**	1	8.38**	1	0.44
Node Quadratic	1	36.02**	1	47.86**	1	5.95*	1	0.58
Node Cubic	-	-	-	-	-	-	-	-
Density L x Node L	1	13.82**	1	2.48	1	14.58**	1	7.93**
Density L x Node Q	1	6.61**	-	-	1	8.00**	1	18.77**

Note: +, *, ** denote significance levels of $P=0.10, 0.05, 0.01$, respectively. N = 264, 258, 212, 168 for All Positions, Positions One, Two, and Three, respectively. Replication not included as a random since it is confound with fitting density in model.

Table 11. Regression coefficients for mean boll weight (g boll^{-1}) from fitting the response surface of plant density (quadratic) and fruiting nodes (cubic) with two interaction terms for the three fields and total fruiting positions on a node, and first, second, and third fruiting positions.

Regression Effect	Total All Positions	First Position	Second Position	Third Position
Ponder Farm 1997				
Intercept	4.3707	4.5301	3.9319	2.9300
Density Linear (DL)	-0.06609	-0.1049	-0.1064	0.05396
Density Quadratic	0.003429	0.006050	0.004952	0.03880
Node Linear (NL)	0.2560	0.2880	0.3157	0.1948
Node Quadratic (NQ)	-0.03227	-0.03709	-0.07652	-0.03369
Node Cubic	---	---	0.003414	---
DL x NL	-0.01154	-0.01705	---	---
DL x NQ	0.001178	0.001890	---	---
CPES Main Campus Pivot 1997				
Intercept	4.0437	4.3509	4.0295	2.9406
Density Linear (DL)	-0.02804	-0.05509	-0.03384	-0.1392
Density Quadratic	0.009153	0.009472	---	0.008740
Node Linear (NL)	0.05814	0.07852	0.02202	0.01014
Node Quadratic (NQ)	-0.00551	-0.01443	-0.00986	---
Node Cubic	-0.00043	---	---	---
DL x NL	-0.00116	---	---	0.02483
DL x NQ	---	---	---	---
Ponder Farm 1998				
Intercept	4.2106	4.5973	4.0418	3.6367
Density Linear (DL)	0.001997	-0.01679	-0.03017	-0.08831
Density Quadratic	-0.4312	---	0.004983	---
Node Linear (NL)	0.1700	0.1513	0.1255	0.04079
Node Quadratic (NQ)	-0.02227	-0.02582	-0.01814	-0.00881
Node Cubic	---	---	---	---
DL x NL	-0.01718	-0.00504	-0.03203	-0.02909
DL x NQ	0.001604	---	0.003745	0.007824

Figure 1. Effect of interaction between plant density and fruiting node on mean boll weight (g boll^{-1}) for total of all node fruiting positions, node fruiting position one, two and three at the Ponder Farm in 1997 in Tift County, Georgia.

Figure 2. Effect of interaction between plant density and fruiting node on mean boll weight (g boll^{-1}) for total of all node fruiting positions, node fruiting position one, two and three at the CPES Main Campus Pivot in 1997 in Tift County, Georgia.

Figure 3. Effect of interaction between plant density and fruiting node on mean boll weight (g boll^{-1}) for total of all node fruiting positions, node fruiting position one, two and three at the Ponder Farm in 1998 in Tift County, Georgia.