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Effects of Plant Density on Boll Retention and Yield of Cotton in the Mid-South

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Abstract

The number of cotton (*Gossypium hirsutum* L.) plants being grown per unit of land area has gained attention due to the technology fees associated with seed containing value added traits. We investigated boll retention, yield, and yield components of cotton grown with reduced stands of 20% to 40% from the uniform planting pattern of four seeds per 30.5 cm of row. Five field experiments were conducted from 2012-2014 using eight treatments arranged in a randomized complete design with six replications. Yield and yield component data were collected. The plant one-row skip one-row treatment resulted in significant yield losses across all five experiments compared to the uniform planting pattern. Treatments with 20% stand reductions did not result in lower total yields; however, each plant in these treatments had to produce two additional bolls to maintain yield. Treatments which had at least 61 cm skips, 40% stand reduction, resulted in lower yields. Treatments had minor affects on boll weight, and lint percentage. The uniform planting pattern produced 67% of its yield from position one bolls compared to about 50% for treatments with reduced stands. Reduced stand treatments produced about 20% of their yield on monopodial branches compared to 10% for the uniform treatment. With modern precision planting equipments, opportunities exist to reduce seed rate and maintain yield; however, many production risk factors must also be considered before a reduced seeding rate is adopted.

Keywords

Cotton, Plant Population, Fruit Retention, Plant Skips

1. Introduction

Even though Upland cotton, *Gossypium hirsutum* L., is widely grown and provides a source of natural fibers for the textile industry, production challenges remain. The current economic climate continues to impact profit margins. With production cost on the rise due in part to increased seed cost associated with transgenic technologies, producers are searching for ways to increase efficiency. This has led to changes in seeding rates, row spacing and row-configurations such as solid planted, twin-rows, and skip-row patterns. With the advent of precision seed drop planters and GPS control systems, producers can manipulate plant populations to optimize yield.

Several studies conducted in the late 1800's and early to mid 1900's suggested that a wide range in plant stand resulted in yields being similar. Plant stands in those studies were sparse compared to today. For example Mayton *et al.* [1] reported on experiments conducted in Alabama from 1924 to 1935. In the first set of experiments conducted during 1924-1929, cotton plants were spaced 6, 12, 18, 30, and 36 inches apart in 3.5 foot rows with one, two, three, and four plants per hill. Based on results obtained, a second set of experiments were conducted from 1930-1934 at five branch stations each year with spacing of 9, 18, and 27 inches with one, three, and six plants per hill at each drill distance. Based on the ten years study, they recommended that cotton be spaced 18 inches apart in the drill with one to three plants per hill.

With the introduction of mechanical harvesters, there was renewed interest in plant stand and population density. Wilkes and Corley [2] reviewed the results of numerous studies and concluded that plant spacing could vary considerably and produce similar yields as long as plants were uniformly distributed. They further reported that 40,000 to 50,000 plants per acre were needed for efficient mechanical harvesting.

Studies have continued to be conducted since the 1970's in cotton using different plant densities and measuring their effects on total yield [3] [4] [5] [6] [7] [8] [9]. A wide range of plant densities (35,000 to 175,000 plants ha^{-1}) resulted in optimum total yields in these studies. O'Berry *et al.* [10] reported that cotton yields were highest with plant populations of 8.9 and 12.8 m^{-2} compared to 5.3 m^{-2} in studies conducted in Virginia and North Carolina, while in Louisiana the highest yields were from 5.8 and 9.5 plants m^{-2} compared to 17.1 plants m^{-2}. McCarty *et al.* [11] reported that plant spacing of 8, 15, 23, and 30 cm resulted in similar yields in 2003, but yields were significantly affected by plant spacing in 2004. Pettigrew *et al.* [12] in a study with obsolete and modern cotton genotypes grown at densities of five plants m^{-2} and 10 plants m^{-2} reported there was no difference in yield between the two densities. Producers today, in the Mid-South, generally use about a 96.5 to 101.5 cm row and plant 3 to 4 seeds 30 cm^{-1} of row, with a final plant population of between 100,000 to 120,000 plants ha^{-1}.

Cotton yield is directly related to the number of bolls retained to harvest and their weight. Boll retention is complex and can be affected by many interacting factors such as genetics, physiology, nutrition, water stress, temperature, competition for photosynthates, insects or a combination of any of these [3] [13] [14] [15] [16]. These same factors can also affect boll weight. The ability to compensate for reduced plant densities by producing more fruit on longer sympodial branches and producing more main stem nodes or the compensation for loss of shed fruit can affect boll retention and weight [3] [17] [18].

Boll retention from Mid-South cotton studies with four seed per 30.5 cm (1 ft) spaced 7.6 cm (3 in) apart show that fruiting sites 1 and 2 on sympodial branches typically produce 50% - 75% and 15% - 20% of total yield, with the remaining 5% - 15% occurring at more distal sites and on monopodial branches [13] [19] [20] [21] [22]. Jenkins *et al.* [21] reported that bolls at fruiting site 1 were 14% heavier than bolls at fruiting site 2 and 21% heavier than those at fruiting site 3 at every node.

The overall goal of this study was to determine the impact of skip size (length) on yield, within canopy yield distribution, and boll size. The objectives of this research were to investigate the effects on boll retention, yield, and yield components of cotton plants grown at different spacing and planting patterns. Treatments were designed to reduced stands approximately 25 and 50% from standard or uniform planting practices.

2. Materials and Methods

2.1. Experimental Site, Design, and Establishment

Experiments were conducted at two locations at the Plant Science Research Center, Mississippi State, MS in 2012-2013 and one location in 2014. The soil type at location one was a Marietta sandy clay loam (fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts) and at location two a Marietta loam (fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts). Based on soil analyses 67 $kgha^{-1}$ of K_2O and 58 $kgha^{-1}$ of N were applied pre-plant to all plots. At pin head square all plots were side dressed with 78 $kgha^{-1}$ of N. Plots were kept weed free by spot spraying with roundup as needed. Insecticides were applied based on scouting and thresholds. Plants were grown under rain fed conditions without supplemental irrigation. Plant growth regulators were not applied to this study. The cotton cultivar PhytoGen® PHY 375 WRF was used in this study as it was the most popular cotton cultivar planted in the U.S. in 2011 occupying 11% of all Upland acres; whereas, in the South Central and Southeast states it was planted on 21 and 22%, respectively [23].

Plots were planted on 21 and 22 May 2012, 15 and 16 May 2013, and 21 May 2014 (**Table 1**). Plots were planted with a six row Monosem® precision vacuum planter (Edwardsville, KS) modified by Seed Research Equipment Solutions (SRES), South Hutchinson, KS for planting research plots. The seeding rate was 13 seed per m spaced 7.6 cm apart. Each plot was six rows wide on 0.97 m centers, with a length of 12 m. Approximately three weeks after emergence each year plots were hand thinned to the desired spacing. The experiment contained eight treatments each replicated six times arranged as a randomized complete block. **Table 2** provides an illustration of how the treatments were laid out in the field. Treatments were 1) Skips 30.5 cm; rows 1, 3, and 5 were not thinned; in rows 2, 4, and 6 the rows were sub-divided into 30.5 cm blocks and in every other block going down the row plants were removed; 2) Skips 61 cm; rows 1, 3, and 5 were not thinned; rows 2, 4, and 6 were sub-divided into 61 cm blocks and

Table 1. Treatments, experiment number, planting and harvest dates for 5 experiments in 2012-2014 at the Plant Science Research Center Farm, Mississippi State, MS.

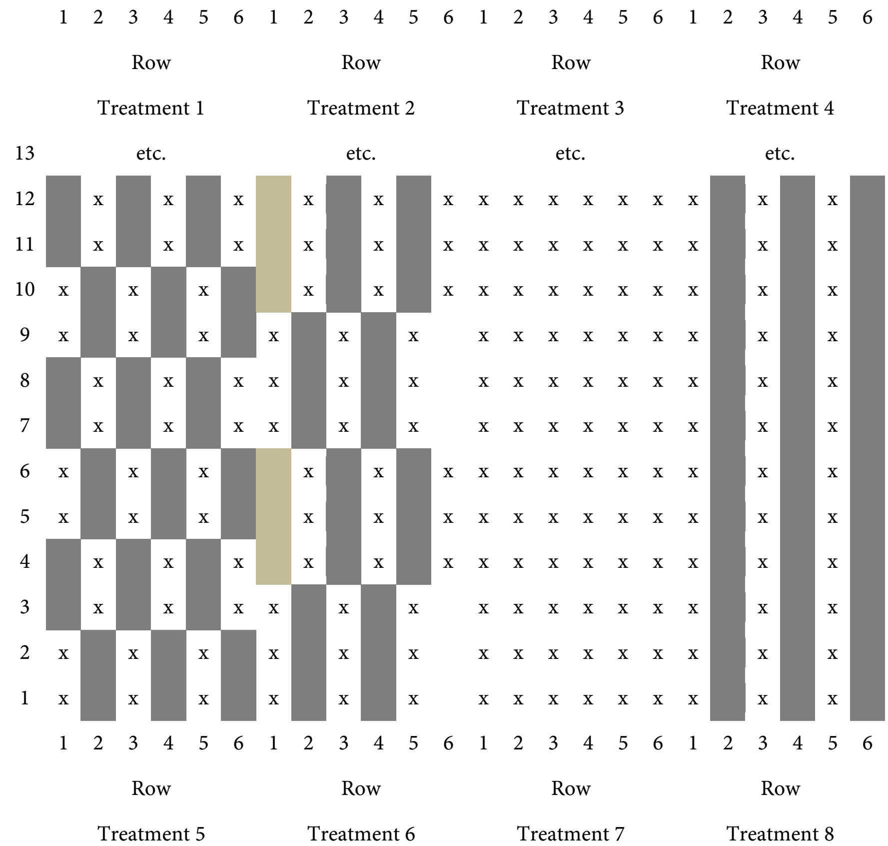
Treatment†			
1. Skip 30.5 cm = row 1, 3, and 5 not thinned; row 2, 4, and 6 with 30.5 cm skips			
2. Skip 61.0 cm = row 1, 3, and 5 not thinned; row 2, 4, and 6 with 61.0 cm skips			
3. Skip 91.5 cm = row 1, 3, and 5 not thinned; row 2, 4 and 6 with 91.5 cm skips			
4. Staggered skip 30.5 cm = row 1, 3, and 5 with 30.5 cm skips; row 2, 4, and 6 with 30.5 cm skips staggered.			
5. Staggered skip 61.0 cm = row 1, 3, and 5 with 61.0 cm skips; row 2, 4, and 6 with 61.0 cm skips staggered.			
6. Staggered skip 91.5 cm = row 1 , 3, and 5 with 91.5 cm skips; row 2, 4, and 6 with 91.5 cm skips staggered.			
7. uniform planting pattern = plant 13 seed per m, spaced 7.62 cm apart			
8. skip-row = plant 1 row, skip 1row			
Location and experiment	Planting date	Box map date	Machine harvest
Loc 1, Exp. 1	22 May 2012	Not mapped	27 Oct 2012
Loc 2, Exp. 2	21 May 2012	29-30 Oct 2012	31 Oct 2012
Loc 1, Exp. 3	16 May 2013	Not mapped	15 Oct 2013
Loc 2, Exp. 4	15 May 2013	23-24 Oct 2013	25 Oct 2013
Loc 1, Exp. 5	21 May 2013	23 - 24 Oct 2014	24 Oct 2014

†All plots were planted at a seeding rate of 13 seeds equally spaced per m of row. In treatments 1 - 3 we created skips of 30.5, 61, and 91.5 cm in every other row in the plot. In treatments 4 - 6 we created skips of 30.5, 61, and 91.5 cm in every row but skips were arranged in a staggered fashion in the plot. Treatment 7 was a uniform planting pattern and 8 was a plant one row, skip one row pattern.

Table 2. Illustrations for the first 3.66 m of row for eight different plant spacing treatments†. Each "x" represents 30.5 cm of row with plants present and the shaded blocks are skips where plants were removed.

13			etc.						etc.						etc.						etc.			
12	x		x		x		x		x		x		x		x		x			x		x		x
11	x	x	x	x	x	x	x		x		x		x		x		x		x		x		x	
10	x		x		x		x	x	x	x	x	x	x		x		x			x		x		x
9	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	
8	x		x		x		x		x		x		x	x	x	x	x	x		x		x		x
7	x	x	x	x	x	x	x		x		x		x	x	x	x	x	x	x		x		x	
6	x		x		x		x	x	x	x	x	x	x		x		x			x		x		x
5	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x		x		x		x	
4	x		x		x		x		x		x		x		x		x			x		x		x
3	x	x	x	x	x	x	x		x		x		x	x	x	x	x	x	x		x		x	
2	x		x		x		x	x	x	x	x	x	x	x	x	x	x	x		x		x		x
1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	

Continued



†Each treatment was 6 rows wide and 12 m long. Treatments were arranged in a RCB design with six replications.

plants were removed in every other block going down the row; 3) Skips 91.5 cm; rows 1, 3, and 5 were not thinned; rows 2, 4, and 6 were sub-divided into 91.5 cm blocks and plants were removed in every other block going down the row; 4) Staggered skips 30.5 cm; all six rows were divided in 30.5 cm blocks and in rows 1, 3 , and 5, plants were removed in blocks 2, 4, 6, etc. and for rows 2, 4, and 6 plants were removed in blocks 1, 3, 5 and etc.; 5) Staggered skips 61 cm; the six rows were divided into 61 cm blocks and in rows 1, 3 , and 5 plants were removed in blocks 2, 4, 6, etc. and for rows 2, 4, and 6 plants were removed in blocks 1, 3, 5 and etc.; 6) Staggered skips 91.5cm; the six rows were divided into 91.5 cm blocks and in rows 1, 3 , and 5 plants were removed in blocks 2, 4, 6, etc. and for rows 2, 4, and 6 plants were removed in blocks 1, 3, 5 and etc.; 7) Uniform planting pattern; the six row plot was not thinned and; 8) Skip-row; row 1, 3, and 5 were not thinned and all plants were removed from rows 2, 4, and 6. In treatments 1 - 3 we created skips of 30.5, 61, and 91.5 cm in every other row in the plot to reduce stand approximately 25%. In treatments 4 - 6 we created skips of 30.5, 61, and 91.5 cm in every row but skips were arranged in a staggered fashion in the plot to reduce stand approximately 50%. Treatment 7 was a uniform planting pattern and 8 was a plant one row, skip one row pattern which reduced stand 50%. Data were collected from the 4 center rows in each treatment.

2.2. End-of-Season Plant Mapping

After defoliation when mature bolls were open, all plants within a continuous 3 m section of row, selected at random in each plot in locations 2, 4, and 5 were mapped following a described procedure [20] [21] which is commonly referred to as box mapping. For treatments 1 - 7, the 3 m sample came from row 2 in each plot and for treatment 8 the sample came from row 3. Briefly, the mapping procedure involves cutting the plants below the cotyledon node, removing monopodial branches and then moving the plants to the mapping area at the edge of the field. The number of plants was recorded for each sample. Bolls from each plant were hand harvested by fruiting site using a harvest box constructed with labeled (node and position) compartments, hence the term box mapping. The number of bolls harvested by fruiting site was recorded and the seed cotton was placed in labeled bags for weighing. Since a limited number of bolls were harvested on fruiting sites beyond position 3 they were combined with position 3 (≥3) for data analyses. The bolls from monopodial branches were counted, harvested by bulk and placed in labeled bags. If there was an aborted terminal plant in a sample that could not be mapped, bolls were counted, harvested and placed in a labeled bag. This allowed us to account for total yield in the 3 m sample. All harvested samples were transported to the laboratory and weighed. From this data we calculated the number of bolls, the weight of seed cotton, and the weight per boll for seed cotton produced at each fruiting site on sympodial branches, and also boll weight and amount of seed cotton produced on monopodial branches. The weight of seed cotton and number of bolls were then converted to percentages for each sympodial fruiting site and the monopodial branch in each sample. The machine harvested seed cotton yield for each treatment was converted to lint yield and this was distributed across fruiting sites according to the percentage distribution from the mapped plants for the three m sample for each plot. Thus, the yields reported are machine-harvest yields from the mean of the four center rows of each plot. In this manuscript mapping data is presented for position 1, position 2, and position ≥ 3 fruiting sites from sympodial branches and for monopodial branches for the eight treatments. Analyses of variances (ANOVA) were conducted using SAS version 9.4 (SAS Institute, Cary, NC) and means were separated using Fisher's protected least significant difference (LSD) at the 0.05 level.

2.3. Yield Data

A 25-boll sample was hand-picked from row 2 and 3 in each plot prior to machine harvest from near the middle nodes of the plants. Samples were ginned on a 10 saw laboratory gin and used to estimate lint percent and boll weight. The average lint percent across reps was used to convert seed cotton yield to lint yield. A commercial cotton picker modified for plot harvesting and weighing was used to determine yield. Plots were machine harvested on 27 and 31 Oct. 2012, 15 and 25 Oct. 2013 for experiments 1, 2, 3 and 4, respectively and 24 Oct. 2014 for experiment 5. Yield data were subjected to ANOVA using SAS version

9.4 (SAS Institute, Cary, NC). Means were separated using Fisher's protected least significant difference (LSD) at the 0.05 level. All F-tests were performed as described by McIntosh [24].

3. Results and Discussion

3.1. Plant Population

All plots were seeded at a rate of 4 seed per 30.5 cm or 135,967 seed per ha. We expected 3 of the 4 seed to germinate and establish which should have resulted in 101,975 plant per ha in treatment 7 (uniform planting pattern). Based on number of plants mapped at the end of the season the number of plants per ha per treatment were as follows: 1). 70,453; 2). 74,750; 3). 73,523; 4). 54,364; 5). 56,629; 6). 52,854; 7). 89,285; and 8). 47,096. Skip treatments 1 - 3, and staggered skip treatments 4 - 6 should have resulted in a 25% and 50% reduction in plant population, which would have been 76,481 and 50,987 plant per ha, respectively. Our uniform planting pattern had about 12,000 fewer plants per ha than expected. Relative to the uniform planting pattern, plant population reductions ranged from 17% - 22% for skip treatments 1 - 3 and 36% - 40% for staggered skip treatments 4 - 6. Treatment 8 (skip-row) was reduced 47%. The reductions in population were less than our goal but they did approximate those we wanted to achieve.

3.2. Yield and Yield Components

3.2.1. Boll Weight

When averaged across all experiments, treatments did not affect boll weight; however, in experiment one in 2012 and experiment three in 2013 some small significant differences were noted (**Table 3**). In a study where plants were spaced from 8 to 30 cm apart, boll weight increased as spacing increased [11]. Bridge *et al.* [5] reported that in a study where plant population ranged from 24,700 to 222,300 plants per ha there was a general decrease in boll weight as plant population increased. Our study involved wider skips, not wider spacing between plants; therefore, we did not expect to see major differences in boll weight.

3.2.2. Lint Percent

Staggered skips of 30.5 and 61 cm, and skip-row produced higher lint percentages than the uniform planting pattern, when averaged across all experiments (**Table 3**) indicating that reducing plant stand by approximately 50% increased lint percent. In four of the five experiments we did not detect a significant difference in mean lint percentage across all treatments. As with boll weight we did not expect to see large differences in lint percentage.

3.2.3. Lint Yield

Treatments significantly affected lint yield (**Table 3**). We expected skip-row (treatment 8) to produce lower yields since yield was calculated on a unit of land area for all treatments. Yield for skip-row was significantly lower than all staggered treatments even though plant populations were similar indicating that

Table 3. Mean boll weight, lint percentage, and lint yield for cotton cultivar PHY 375 WRF grown in different plant spacing treatments in 5 experiments in 2012-2014 at the Plant Science Research Center Farm, Mississippi State, MS.

	Exp. 1	Exp. 2	Exp. 3	Exp 4.	Exp. 5	Mean
Treatment†			Boll weight			
	g	g	g	g	g	g
1. Skip 30.5	5.42	5.25	5.31	5.55	5.46	5.40
2. Skip 61.0	5.34	5.17	5.36	5.28	5.35	5.30
3. Skip 91.5	5.70	5.14	5.11	5.40	5.34	5.34
4. Staggered 30.5	5.72	5.24	5.22	5.42	5.28	5.38
5. Staggered 61.0	5.43	5.30	5.20	5.48	5.48	5.38
6. Staggered 91.5	5.42	5.17	5.34	5.39	5.35	5.34
7. uniform	5.50	5.22	5.23	5.37	5.23	5.31
8. skip-row	5.43	5.46	5.56	5.29	5.38	5.42
Trt F	*	ns	*	ns	ns	ns
Trt by Exp F						*
Trt LSD (0.05)	0.25		0.24			0.11
			Lint percentage			
	%	%	%	%	%	%
1. Skip 30.5	42.06	42.05	43.97	45.17	46.36	43.92
2. Skip 61.0	43.08	42.04	43.78	45.04	46.61	44.11
3. Skip 91.5	42.97	41.73	44.07	44.83	46.41	44.00
4. Staggered 30.5	43.17	42.28	44.54	44.86	46.62	44.29
5. Staggered 61.0	42.88	42.72	43.72	45.43	46.77	44.31
6. Staggered 91.5	42.80	42.02	43.70	45.39	46.13	44.01
7. uniform	42.64	41.63	43.58	44.82	46.44	43.82
8. skip-row	43.03	42.59	44.19	45.12	46.64	44.31
Trt F	ns	ns	*	ns	ns	**
Trt by Exp F						ns
Trt LSD (0.05)			0.58			0.32
			Lint yield			
	$kg\cdot ha^{-1}$	$kg\cdot ha^{-1}$	$k\cdot ha^{-1}$	$kg\cdot ha^{-1}$	$kg\cdot ha^{-1}$	$kg\cdot ha^{-1}$
1. Skip 30.5	1591	1473	1268	1525	1648	1501
2. Skip 61.0	1691	1418	1405	1536	1685	1547
3. Skip 91.5	1681	1347	1360	1550	1679	1524
4. Staggered 30.5	1708	1431	1288	1296	1654	1476
5. Staggered 61.0	1616	1325	1182	1511	1684	1463
6. Staggered 91.5	1517	1263	1099	1374	1636	1378
7. uniform	1660	1302	1440	1515	1775	1538
8. skip-row	1242	1026	903	1072	1194	1087
Trt F	**	**	**	**	**	**
Trt by Exp F						*
Trt LSD (0.05)	121	102	151	245	122	68

*, **significant at the 0.05 and 0.01 levels of probability, respectively; †See table 1 and 2 for treatment description; ‡ns, nonsignificant at the 0.05 probability level.

planting pattern was important in determining total yield. The uniform planting pattern was not significantly different from all skip treatments and staggered skips of 30.5 cm when averaged across all experiments. Previous studies have shown a wide range in plant populations can result in similar yields; however, most of these studies were conducted with uniform stands. In the current study we reduced plant population by creating different length skips going down the row in the plot. Staggered skips of 61 cm reduced stand about 36% and yield was only decreased in one of five experiments compared to the uniform planting pattern. Averaged over the five experiments, only staggered skips of 91.5 cm and skip-row resulted in significant lower yields compared to the uniform planting pattern. There was a small treatment by experiment interaction. The skip-row pattern resulted in significantly lower yield compared to the uniform planting pattern in all experiments; whereas, in experiments 1 and 5 only staggered skips of 91.5 cm was lower than the uniform planting pattern. Heilman *et al*. [25] found that in single drill cotton rows in the Rio Grande Valley of Texas, stand losses of 25 and 40% resulted in 16.8 and 23.2% reduction in yield. In a four year test on the High Plains of Texas, a 25% plant loss resulted in significant yield losses 3 out of 4 years [26].

3.2.4. End-of-Season Plant Mapping

The data for mapping are averaged across the three experiments that were mapped (one experiment each year). Lint yields produced on position 1, 2, and ≥ 3 fruiting sites on sympodial branches were significantly affected by treatments (**Table 4**). Uniform planting pattern produced significantly more yield and skip-row produced significantly less yield on position 1 sites than other treatments. Cumulative yield for first position fruiting sites was higher at each main stem node above 8 for the uniform planting pattern compared to the other treatments (data not shown). More lint was produced on position 2 sites for all skip treatments and staggered skips of 30.5 cm compared to the uniform treatment. All treatments produced greater yields than the uniform planting pattern on position ≥ 3 sites, except the skip-row. Also, all treatments produced greater yields from monopodial branches compared to the uniform treatment. When we examined cumulative yields across position 1, 2, ≥ 3 and monopodial branches, the only treatments that were different from the uniform planting pattern were staggered skips of 91.5 cm and skip-row (**Table 4**); however, the uniform planting pattern accumulated higher yields at all main stem nodes (data not shown). Yield differences for all skip treatments and staggered skips of 30.5 and 61 cm were compensated by greater yields being produced on position 2 and ≥ 3 fruiting sites and monopodial branches compared to the uniform planting pattern.

Sixty-seven percent of total yield for the uniform planting pattern was produced on position 1 fruiting sites (**Table 5**). All other treatments produced from 50% to 55% of their total yield on position 1 fruiting sites. Percent of yield produced on position 2 sites across treatments was similar and ranged from 18% - 21%. All treatments with some forms of skip produced a higher percent of their yield on position ≥ 3 sites and monopodial branches compared to the uniform

Table 4. Mean lint yield for position (Pos) 1, 2, and ≥ 3 fruiting sites on sympodial branches, and monopodial (Mon) branches for three experiments (Exp) conducted in 2012-2014 at the Plant Science Research Center Farm, Mississippi State, MS.

						F test					F test		
	Pos1	Pos2	Pos ≥ 3	Mon	LSD(0.05)†	Pos	P × Exp	Pos 1 + 2 + ≥ 3	Mon	LSD (0.05)‡	Pos	P × Exp	Total
	Lint yield kg ha^{-1}							Lint yield kg ha^{-1}					
Trt													
1. Skip 30.5	785	329	121	319	50	**	**	1235	319	88	**	ns	1555
2. Skip 61.0	827	319	119	283	54	**	ns§	1265	283	90	**	ns	1548
3. Skip 91.5	832	302	136	255	53	**	*	1270	255	87	**	ns	1525
4. Staggered 30.5	757	316	104	283	43	**	**	1177	283	77	**	ns	1460
5. Staggered 61.0	768	297	123	318	64	**	*	1188	318	128	**	ns	1506
6. Staggered 91.5	696	294	126	291	52	**	*	1116	291	105	**	ns	1407
7. uniform	1013	283	72	164	59	**	ns	1369	164	88	**	ns	1533
8. skip-row	591	233	87	186	46	**	ns	911	186	75	**	ns	1097
Trt F	**	**	**	**				**	**				**
Trt × Exp F	ns	*	ns	ns				ns	ns				ns
Trt LSD (0.05)	69	33	36	55				78	55				99

*, **significant at the 0.05 and 0.01 levels of probability, respectively; †LSD (0.05) for Pos1 vs Pos2 vs Pos ≥ 3 vs monopodial; ‡LSD (0.05) for (Pos1 + Pos2 + Pos ≥ 3) vs monopodial; §ns, nonsignificant at the 0.05 probability level.

Table 5. Mean percent yield for position (Pos) 1, 2, and ≥ 3 fruiting sites on sympodial branches, and monopodial (Mon) branches for three experiments (Exp) conducted in 2012-2014 at the Plant Science Research Center Farm, Mississippi State, MS.

						F test					F test		
	Pos1	Pos2	Pos ≥ 3	Mon	LSD (0.05)†	Pos	P × Exp	Pos 1 + 2 + ≥ 3	Mon	LSD (0.05)‡	Pos	P × Exp	Total
	Percent yield (%)							Percent yield (%)					
Trt													
1. Skip 30.5	51.0	21.2	7.5	20.4	3.7	**	**	79.7	20.4	3.9	**	**	100.0
2. Skip 61.0	54.0	20.8	7.3	17.9	3.8	**	**	82.1	17.9	4.5	**	**	100.0
3. Skip 91.5	54.9	20.0	8.7	16.4	3.3	**	**	83.6	16.4	4.3	**	**	100.0
4. Staggered 30.5	52.4	21.7	7.1	18.9	3.5	**	ns§	81.2	18.9	4.3	**	ns	100.0
5. Staggered 61.0	51.7	19.7	7.9	20.7	4.3	**	**	79.3	20.7	6.9	**	ns	100.0
6. Staggered 91.5	50.1	20.9	8.6	20.4	3.7	**	**	79.6	20.4	6.0	**	*	100.0
7. uniform	66.9	18.5	4.4	10.2	3.5	**	**	89.8	10.2	3.5	**	**	100.0
8. skip-row	53.9	21.4	7.9	16.8	3.7	**	*	83.2	16.8	5.4	**	*	100.0
Trt F	**	**	**	**				**	**				
Trt × Exp F	ns	*	ns	ns				ns	ns				
Trt LSD (0.05)	4.6	1.8	2.2	3.2				3.2	3.2				

*, **significant at the 0.05 and 0.01 levels of probability, respectively; †LSD (0.05) for Pos1 vs Pos2 vs Pos ≥ 3 vs monopodial; ‡LSD (0.05) for (Pos1 + Pos2 + Pos ≥ 3) vs monopodial; §ns, nonsignificant at the 0.05 probability level.

planting pattern. A higher percent of yield for all skip and staggered skip treatments and skip-row came from monopodial branches and ranged from 16% - 21% compared to 10% for the uniform panting pattern treatment (Table 5).

Bolls from position 1 fruiting sites for the uniform planting pattern were more numerous but significantly lighter compared to other treatments (Table 6). All lower plant population treatments had heavier position 1 bolls than the uniform planting pattern. There were no significant differences in boll weight among any treatments for position 2 and ≥ 3 fruiting sites and monopodial bolls. Monopodial bolls tended to be heavier than those produced on sympodial fruiting sites for most treatments.

The uniform planting pattern produced more position 1 bolls than other treatments (Table 7). Skip and staggered skip treatments produced a similar number of position1 bolls. Lower plant populations, except skip-row, produced more bolls on position 2 and ≥ 3 fruiting sites and on monopodial braches relative to the uniform planting pattern. Greater compensation occurred as monopodial bolls in lower plant population treatments. This resulted in total number of bolls, except for skip-row, being not significantly different from the uniform planting pattern (Table 7).

Average number of bolls per plant was calculated from machine harvest data and is interesting (Table 8). As the plant stand was reduced about 20% in skip treatments 1 - 3, the number of bolls per plant was 9.1, 8.8, and 8.8, respectively. For reductions in plants of about 40%, the number of bolls per plant was 11.5, 10.9, and 11.4 in staggered skip treatments 4 - 6, respectively. However, a 50%

Table 6. Mean boll weight for position (Pos) 1, 2, and ≥ 3 fruiting sites on sympodial branches, and monopodial (Mon) branches for three experiments (Exp) conducted in 2012-2014 at the Plant Science Research Center Farm, Mississippi State, MS.

						F test					F test	
	Pos1	Pos2	Pos≥3	Mon	LSD (0.05)†	Pos	P×Exp	Pos 1+2+≥3	Mon	LSD (0.05)‡	Pos	P×Exp
			Boll weight (g)						Boll weight (g)			
Trt												
1. Skip 30.5	4.31	4.16	3.80	4.68	0.29	**	ns§	4.14	4.68	0.28	**	ns
2. Skip 61.0	4.24	4.19	3.84	4.37	0.29	**	ns	4.13	4.37	0.20	*	ns
3. Skip 91.5	4.28	4.18	3.68	4.53	0.26	**	ns	4.10	4.53	0.34	*	ns
4. Staggered 30.5	4.22	4.06	3.60	4.57	0.27	**	ns	4.02	4.57	0.23	**	ns
5. Staggered 61.0	4.29	4.13	3.83	4.71	0.23	**	*	4.13	4.71	0.22	**	ns
6. Staggered 91.5	4.40	4.11	3.89	4.65	0.21	**	*	4.17	4.65	0.23	**	ns
7. uniform	3.97	4.00	3.74	4.44	0.41	**	ns	3.91	4.44	0.38	**	ns
8. skip-row	4.22	3.95	3.78	4.58	0.24	**	ns	4.03	4.58	0.33	**	ns
Trt F	**	ns	ns	ns				ns	ns			
Trt × Exp F	ns	ns	ns	ns				ns	ns			
Trt LSD (0.05)	0.19	0.24	0.37	0.41				0.17	0.41			

*, **significant at the 0.05 and 0.01 levels of probability, respectively; †LSD (0.05) for Pos1 vs Pos2 vs Pos ≥ 3 vs momopodial; ‡LSD (0.05) for (Pos1 + Pos2 + Pos ≥ 3) vs monopodial; §ns, nonsignificant at the 0.05 probability level.

Table 7. Mean number of bolls per hectare for position (Pos) 1, 2 and ≥ 3 fruiting sites on sympodial branches, and monopodial (Mon) branches for three experiments (Exp) conducted in 2012-2014 at the Plant Science Research Center Farm, Mississippi State, MS.

						F test					F test		
	Pos1	Pos2	Pos ≥ 3	Mon	LSD (0.05)†	Pos	P×Exp	Pos 1 + 2 + ≥ 3	Mon	LSD (0.05)‡	Pos	P × Exp	Total
		Number bolls ha^{-1}							Number bolls ha^{-1}				
Trt													
1. Skip 30.5	323,047	145,181	60,243	126,158	21,778	**	**	528,471	126,158	39,604	**	**	654,629
2. Skip 61.0	356,323	147,620	58,107	121,112	22,608	**	**	562,050	121,112	44,309	**	**	683,162
3. Skip 91.5	335,129	129,335	64,727	105,106	23,377	**	*	529,191	105,106	37,481	**	*	634,297
4. Staggered 30.5	320,063	146,383	55,535	112,882	17,696	**	**	521,981	112,882	42,848	**	ns	634863
5. Staggered 61.0	341,014	145,417	66,706	137,194	26,281	**	**	553,138	137,194	48,522	**	*	690,331
6. Staggered 91.5	332,242	153,009	69,618	137,538	25,192	**	ns§	554,869	137,538	50,028	**	ns	692,407
7. uniform	415,728	122,601	34,954	61,392	22,019	**	**	573,282	61,392	35,873	**	*	634,675
8. skip-row	275,939	120,075	47,886	85,782	15,821	**	**	443,899	85,782	27,909	**	*	529,682
Trt F	**	**	**	**				**	**				**
Trt × Exp F	ns	ns	ns	ns				ns	ns				ns
Trt LSD (0.05)	31,134	20,134	19,774	28,112				52,972	28,112				69,467

*, **significant at the 0.05 and 0.01 levels of probability, respectively; †LSD (0.05) for Pos1 vs Pos2 vs Pos3 vs momopodial; ‡LSD (0.05) for (Pos1+ Pos2+ Pos3) vs monopodial; §ns, nonsignificant at the 0.05 probability level.

Table 8. Machine harvest seed cotton yield, number of bolls, and number of bolls per plant for five experiments conducted in 2012-2014 at the Plant Science Research Center Farm, Mississippi State, MS.

Treatment†	Seed cotton	Bolls‡	Plants	Bolls per plant
	kg ha^{-1}	Number ha^{-1}	Number ha^{-1}	Number
1. Skip 30.5	3480	641,214	70,453	9.1
2. Skip 61.0	3466	567,323	74,750	8.8
3. Skip 91.5	3434	648,680	73,523	8.8
4. Staggered 30.5	3274	616,826	54,364	11.5
5. Staggered 61.0	3341	616,826	56,629	10.9
6. Staggered 91.5	3155	602,623	52,854	11.4
7. uniform	3442	652,734	89,285	7.3
8. skip-row	2448	457,050	47,096	9.8
LSD (0.05)	221	38,387		0.6

†See Table 1 and Table 2 for treatment description; ‡Number of bolls per hectare was calculated from machine harvest seed cotton yield using average boll weight for the 50 boll sample.

reduction in plants in the skip-row produced 9.8 bolls per plant. These can be compared to the uniform planting pattern where 7.3 bolls were produced per plant. The cotton plant has the ability to compensate, produce and retain more open bolls in reduced stands; however, these bolls may be produced later in the growing season. A later maturing crop and the requirement that each plant must produce and mature more bolls in reduced stands could increase production risk. This risk would need to be compared to cost savings of fewer seed in the final decision concerning plant population.

In this three year study our uniform planting pattern stand was about 90,000 plants per hectare from a seeding rate of about 136,000 per hectare (13 seed per m). We used a precision drop planter and commercial seed. The commercial seed had an 80 + percent germination; however, we must remember that standard germination test is conducted under temperature and moisture conditions favorable for germination. Adverse environmental conditions such as cool temperatures and dry and crusty soils can impact stand establishment. Seed quality becomes an important consideration when considering reducing seed rate. Reduced seeding rates coupled with adverse plantings conditions could result in a less than adequate stand resulting in lower yield or in a decision to re-plant. Even though modern precision planting equipments allow accurate seed drop, many interacting factors, some of which cannot be controlled (seed quality, temperature, soil moisture, disease pressure, soil structure, and etc.), determine germination and stand establishment.

The plant one-row skip one-row planting pattern which reduced plant population by 50% resulted in significant yield losses across five experiments conducted from 2012-2014 compared to the uniform planting pattern of 13 seed per m of row. Even though down-the-row cost is reduced in skip-row cotton, yields have been reported to be 67% to 92% of solid planting depending on soil type and planting pattern [27] [28]. Jost *et al.* [29] reported in Georgia that skip-row yields averaged 78% of solid planted across a wide yield range. Skip treatments of 30.5, 61, and 91.5 cm which reduced stand by about 20% did not result in lower total yields. Staggered skips of 61 and 91.5 cm reduced stands about 40% and resulted in lower yields compared to the uniform planting pattern, when averaged across experiments. However, in some environments (experiments) compensation occurred in the lower plant populations and yields were not reduced. Treatments had minor affects on the yield components boll weight, and lint percentage.

Plant mapping revealed that lower plant stands, compensated with increased boll retention on position 2 and ≥3 fruiting sites and increased retention on monopodial braches. Plants in the uniform planting pattern produced 67% of its yield from position1 bolls; whereas, skip and staggered skip treatments with 20% - 40% reduced stands only produced about 50% of their total yield on position 1 fruiting sites. On the other hand, skip and staggered skip treatments produced about 20% of their yield on monopodial branches compared to 10% for the uniform planting pattern. In some environments this could result in a delay in harvest since position 2, ≥3, and monopodial bolls are set later than position 1 bolls. With adverse weather conditions, delayed harvest could result in reduced yield and quality. With modern precision planting equipments opportunities exist to reduce seed rate without negatively impacting yield; however, there are risks that must also be considered before a reduced seeding rate is adopted.

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