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AGRONOMY AND SOILS

Cotton Yield and Quality Response to Row Pattern and Seeding Rate

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ABSTRACT

Cotton (*Gossypium hirsutum* L.) is a major rotational crop associated with peanut (*Arachis hypogaea* L.) cropping systems in Southwest Georgia. Since peanut is typically planted in twin-rows for greater yield and grade, use of the same twin-row planter for cotton would be cost effective. It is not clear what effect row pattern would have on cotton lint yield using drip irrigation. The objectives were to compare cotton yield when planted in different row patterns, with two plant densities, at multiple locations, and irrigated with drip and sprinkler irrigation systems. Cotton was planted in single- and twin-row patterns at recommended (1X) and half-recommended (0.5X) seeding rates (93,000 and 54,600 seeds/ha, respectively). Irrigation systems were subsurface drip irrigation (SSDI), shallow subsurface drip irrigation (S3DI), and overhead sprinkler. Row pattern (single- or twin-row), seeding rate, or irrigation system had no effect on lint yield. There were fiber quality differences, probably due to cultivar, but there was no consistency to draw any conclusions. For consistent year-to-year yield and economics, it is recommended to plant cotton near 1X seeding rates using single- or twin-rows with either drip or sprinkler irrigation systems. Seeding rates reduced to half or lower than the recommended rate may increase risk of lower yields and revenue that may not be covered by money saved using less seed.

Cotton (*Gossypium hirsutum* L.) is grown on about 0.9 million ha in the tri-state area of Alabama, Florida, and Georgia. Cotton is grown in rotation with corn (*Zea mays* L), peanut (*Arachis hypogaea* L.), soybean (*Glycine max* L.), sorghum (*Sorghum bicolor* L.) and wheat (*Triticum aestivum* L.). However, the major cropping sequence in the southeastern United States would be cotton, corn, and peanut with multiple years of either cotton or corn before planting peanut. Cotton is typically planted in single rows whereas peanuts are typically planted in twin-rows for greater yield and grade. It would be cost effective to use a twin-row planter that is typically used for peanut to plant cotton, resulting in reduced machinery and maintenance costs for two separate planters.

Single- versus twin-row production systems have been used in many crops resulting in neutral, positive, or negative yield responses depending on location, environment, plant population, or other experimental treatments or conditions (Bruns et al., 2012; Kratochvil and Taylor, 2005; Mackey et al., 2016; Molin, 2010; Sorensen et al., 2021; Stone et al., 2008; Widdicombe, and Thelen, 2002;). The current recommendation for peanut is to plant in a twin-row pattern for greater yield and grade (Beasley et al., 2000; Baldwin, 1997; Baldwin et al., 2000; Sorensen et al, 2005). Balkcom et al. (2010) demonstrated that cotton row spacings of 38 and 102 cm had little effect on plant growth or yield. They also showed that tillage or herbicide technology, along with row spacing had little effect on yield. Boykin and Reddy (2010) using multiple row spacings and plant populations showed no difference in fiber quality across treatments. There were some differences with fiber quality for specific treatments but no consistency across years or cultivars tested. Stephenson et al. (2011) compared two twin-row (18 and 38 cm centered on 96 cm row), and one single-row pattern (96 cm) with five plant populations to determine the impact on yield and grade of cotton. There was no effect due to row pattern on plant structure, seed variables, lint yield, or fiber quality. Also, plant density had no effect on yield or fiber quality factors. Fromme et al. (2014) showed that solid rows produced 27% greater lint yield than cotton grown using a skip-row pattern with the same seeding rate. Pettigrew (2015) planting various cotton genotypes in a single (101 cm) row versus twin-row pattern (23 cm twin centered on 101 cm row), showed no difference in lint yield, fiber quality, or yield components. Pinnamaneni et al. (2020) showed that cotton grown using a twin-row

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pattern increased lint yield compared with single row by an average of 14% using flood irrigation in a two-year study with a plant population of about 120,000 plants/ha.

Cotton production relies on the proper supply of plant-available nitrogen (N). Bucks et al. (1988) and Henggeler (1988) showed that subsurface drip irrigation (SSDI) was effective in cotton production and would allow precise application of fertilizer N to the cotton crop during an irrigation event. When irrigating daily, fertilizer N can be applied with each irrigation event. Bauer et al. (1997) used a SSDI system to apply the total season fertilizer N (side dress) in one application, five equal weekly increments, or as recommended by computer model (GOSSYM/COMAX). They showed that SSDI lateral spacing, or fertilizer N application method had no effect on cotton yield and that SSDI could have significant fertilizer N savings below the current recommended rates. Sorensen et al. (2006) showed that SSDI could be used to supply fertilizer N to a cotton crop without detrimental effects to yield or quality. They also showed that N applied at 84 kg N/ha had the same yield and grade as cotton supplied 100 kg N/ha.

The effect of row pattern (i.e., twin-row) on the yield or grade of cotton, seems to depend on location, soil type, irrigation system selection, climatic patterns, or other management criteria. However, no research with twin-rows has been done using shallow subsurface drip irrigation (S3DI). In addition, most previous research increased the seeding rate or slightly decreased the seeding rate, with little research done using plant populations at half the recommended seeding rates or lower. Adams et al. (2019) showed that in Texas, cotton yield dropped radically when populations were below 35,000 plants/ha. Lint yield did not seem to be affected by plant population ranging from 35,000 to 129,000 seeds/ha. However, Adams et al (2019) suggested that plant populations greater than 81,000 plants/ha may result in economic loss to producers due to excessive seed cost.

Irrigation systems can apply water to the soil to reduce the effects of drought during the growing season. Also, the type of irrigation system, either drip or sprinkler irrigation, may influence yield of these crops. Therefore, the objectives of this research were to document cotton yield and fiber quality when: 1) planted in twin-rows, 2) seeded at recommended (1X) and half-recommended (0.5X) rates, and 3) with various N rates (2003 and 2004) when irrigated with sprinkler or drip systems (SSDI or S3DI).

MATERIALS AND METHODS

Cotton was planted at multiple locations and years, described in Table 1. In 2018, cotton was planted at multiple locations, however, due to Hurricane Michael on 10 Oct. 2018, all cotton plots were destroyed.

Table 1. Project characteristics by location, cultivar, year, and irrigation system selected.

Location	Cotton Cultivar[z]	Study Year	Irrigation System[y]
Bolton	PHY499	2016-2018[x]	Sprinkler
HERC	PHY499	2018	Sprinkler
HERC	PHY480	2019	Sprinkler
Newman	PHY499	2016-2017	S3DI
Newman	PHY480	2018-2019	S3DI
Sasser	DPL555	2003-2004	SSDI
Shellman	DPL555	2003-2004	SSDI
Shellman	PHY499	2016-2017	SSDI
Shellman	PHY499	2017	S3DI
Shellman	PHY480	2018	S3DI

[z] DP= Deltapine (Bayer Group: dekalbasgrowdeltapine.com); PHY= Phytogen (Dow AgroSciences LLC, Indianapolis, IN: phytogencottonseed.com).

[y] Sprinkler = overhead irrigation; S3DI = shallow subsurface drip irrigation; SSDI = subsurface drip irrigation.

[x] Cotton yields were not collected in 2018 at any site due to Hurricane Michael.

Sasser. The Sasser site (2003-2004) was installed 5 km north of Sasser, GA (31°44’12” N, 84°20’47” W) on a Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 0 to 5% slope. A subsurface drip irrigation system (SSDI) was installed in the spring of 1998 with drip laterals buried at 30 cm deep and spaced at 0.91 m with emitters spaced at 30 cm (Netafim USA, Fresno, CA, Typhoon 630, 10 mil). Water flow rate was 1.67 L/min per 30 m of tubing. Drip tubing was installed on 0.76 ha that was divided into six separate stations of 0.12 ha each. Each individual station was 39 m long and 28.5 m wide. Sub-plots were 1.83 m wide and 39 m long with three replications in a split plot (N treatments) with single- and twin-row treatments in a randomized complete block design per N treatment. Planted rows were orientated north to south with a southern aspect. Crop rotation consisted of cotton, corn, and peanut in a three-year rotation.

Shellman. The Shellman site (2003-2004; 2016-2018) had a subsurface drip irrigation system (SSDI) installed in 2001 on a Greenville sandy loam (fine, kaolinitic, thermic Rhodic Kandiudults) located 0.6 km south of Shellman, GA (31º44'44" N, 84º36'30" W). Thin-wall drip tubing with emitters spaced at 45 cm was installed 30 cm deep (Netafim USA, Fresno, CA; Typhoon 630, 15 mil). Drip tubing was spaced 0.91 m apart and had an emitter flow rate of 0.91 L/min per 30-m of tubing. Crop rows were orientated east to west on a 0 to 1% slope. Drip tubing was installed on 1.52 ha and divided into six separate stations of 0.25 ha each. Each station was 46 m long and 49 m wide with 54 crop rows. Sub-plots, row pattern, and plant density, were 5.5-m wide (six rows) by 46 m long with four replications per treatment. Crop rotation for this site was cotton, corn, peanut in a three-year rotation.

Newman. The Newman farm (2016-2019) was located west of Dawson, GA (31º47'3" N, 84º29'15" W) on Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 0 to 2% slope. Shallow subsurface drip irrigation systems (S3DI) were installed with drip laterals buried 5 cm soil depth with laterals spaced 1.83-m apart in alternate row middles. After the crop was planted, drip tubing was installed and connected to a water source. Drip tubing had a water flow rate of 1.5 L/min per 30-m with emitters spaced every 30 cm (Netafim USA, Fresno, CA; Streamline 630, 8 mil). The total plot area was 33 m wide and 52 m long. The plot was then divided perpendicular in the middle such that individual plots were 5.5 m wide and 24 m long. Each plot consisted of six crop rows spaced 0.91 m apart with four replications per treatment. Crop rotation for this site was cotton, cotton, corn, and peanut in a four-year rotation.

Bolton. The Bolton farm (2016-2019) was located west of Dawson, GA (31º47'35" N, 84º30'50" W) on a Red Bay fine sandy loam (fine-loamy, kaolinitic, thermic Rhondic Kandiudults) with 0 to 5% slope. The area was irrigated with a furrow-guided overhead sprinkler lateral system. There were four tiers parallel to the length of the overhead lateral sprinkler system consisting of three spans and an overhang. Crop rows ran perpendicular (east to west) to the length of the system but parallel to the travel of the system. Each individual tier was 61 m wide and 168 m long. Crop rotation had four years between peanut, i.e., cotton, corn, corn, peanut, rotation. Individual plots were 5.5 m wide and 61 m long with four replications per treatment.

HERC. The HERC farm (2018-2019) was located about five km southeast of Dawson, GA (31°43'58.5"N, 84°23'42.8"W) on a Greenville sandy loam (fine, kaolinitic, thermic Rhodic Kandiudults) with 2 to 5% slope. This area was irrigated with a furrow guided mini-linear overhead lateral irrigation system with three spans about 46 m wide. Crop rows ran perpendicular to the length of the system but parallel to the travel of the system and the plot had a north aspect. The typical rotation was two years of cotton with one year of peanut. The field was 91 m wide and 91 m long. Individual plots were 5.5 m wide and 91 m long with four replications per treatment.

Research Treatments. Research treatments were similar across all sites, soil series, and irrigation systems. Plant and harvest dates for all years and locations were within recommended time periods.

There were two row patterns which included single- and twin-row. The single rows were spaced 0.91 m apart while the twin-rows were centered on 0.91 m row with twin-rows spaced between 15 to 23 cm depending on the planter used. In 2003 and 2004, at both Sasser and Shellman site, cotton seed was planted using a twin-row, double disk opener, vacuum planter (Monosem, Inc., Edwardsville, KS, 66111) at recommended seeding depth. All plots had the same width of 5.6 m or six crop rows. Plot length varied by site ranging from 21 m to over 152 m.

After the 2004 growing season, all crops were planted with a JD7300, six-row (John Deere, Moline, IL) double disk opener, vacuum planter at recommended seeding depth set on 0.91-m row spacing. Twin-row planting was accomplished using GPS by shifting the tractor 7.5 cm to the left and right of a 0.91 m center, to get a 15 cm middle between the twin-rows.

For cotton, 8.2 seeds/m (93,000 seeds/ha) was identified as the recommended seeding rate (1X) (Georgia cotton production guide, 2018). A minimum seeding rate of 5 to 5.7 seeds/m is presented as a tradeoff for economizing with expensive transgenic cotton (Georgia cotton production guide, 2018; Stephenson et al. 2011; Adams et al., 2019). It must be noted that reducing seeding rates below 8.2 seeds/m may increase the chance of poor stand establishment, adverse effects on plant canopy structure or architecture, and lint yield, especially if environmental conditions are not suitable for rapid stand establishment (Georgia cotton production guide, 2018). Five seeds/m (54,600 seeds/ha) was chosen as the half-recommended rate (0.5X) and would be at the lower range of the seeding rate. The vacuum planter was adjusted to have the same seeding rate for the 1X and 0.5X across years and locations and with both single and twin-row patterns.

All sites used a randomized complete block design with three to four replications (see individual site description) depending on total plot size. The only site that was different was the HERC site that used a randomized complete block design with four replications per treatment.

Land Preparation and Crop Management. With SSDI and sprinkler systems, land preparation started in late fall with disk harrowing and shallow chisel plowing in the SSDI areas so as not to disturb the buried drip laterals. In S3DI, if the prior crop was cotton or corn, the stalks were pulled and left on the soil surface for cover. At the Bolton and HERC sites, plot areas were cultivated to smooth out the soil surface and a cover crop of rye (*Secale cereale*) or wheat (depending on seed availability) was planted. At about 30 d prior to planting spring crops, the cereal crop was sprayed with contact herbicides to kill all existing foliage. Five d prior to planting, the area was strip tilled at 0.91 m spacing and cultipacked to flatten out the crop rows as needed.

In early spring, soil samples were collected to determine any fertilizer deficiencies and recommendations. Fertilizer application applied the minimum amount of N that could be used with the blended fertilizer types available from local dealers. The SSDI and sprinkler plots were disk harrowed, fertilizer and preplant herbicides were applied and incorporated using a field cultivator, then the soil was cultipacked for a firm seed bed. For the S3DI plots, fertilizer and preplant herbicides were applied prior to strip tillage. Following strip tillage, the plots were cultipacked for a firm seed bed.

Table 1 shows the crop cultivar planted across years and locations. The crop rotation was such that cotton was always planted following peanut. During the growing season, the crop was scouted weekly. At all sites, herbicides, insecticides, or fungicides were applied when needed at recommended rates and timing following manufacturers recommendations.

In 2003 and 2004, at both the Sasser and Shellman sites, there were fertilizer N treatments of 67 and 112 kg N/ha. In later research all fertilizer N was applied at the same rate. Supplemental fertilizer N (32-0-0) was applied through the SSDI and S3DI irrigation systems when possible, depending on N source, labor, and time constraints. Some years, 32-0-0 was not available locally and 28-0-0 was substituted and applied using a ground applicator. With the drip systems, fertilizer N applied using the ground applicator coincided with a rainfall to incorporate the N. Nitrogen was applied through the drip systems at 11 to 22 kg N/ha per week after the first 30 d after emergence, with all the total N being applied by 90 d after emergence. For the sprinkler systems, supplemental fertilizer N (28-0-0) was applied using a ground applicator in two to three applications depending on manpower and N applicator availability. Total N applied to cotton through the drip system or with the ground applicator did not exceed 90 kg N/ha.

Cotton defoliation and boll opening chemicals were applied at the appropriate time and rate depending on weather conditions. Cotton was harvested using a two-row spindle picker. Seed cotton was collected in bags, weighed, a subsample removed, ginned on a table-top gin, and the lint sent to a USDA classing office for fiber quality analysis.

Irrigation Scheduling. Irrigation events were scheduled to maintain soil moisture at levels where drought stress would be minimal and not affect crop yield. SSDI systems at Sasser and Shellman were automated using an electronic datalogger (Campbell Scientific, Inc., CR-23X). The datalogger was also connected to an onsite weather station (Sasser and Shellman). The datalogger collected meteorological data and estimated potential evapotranspiration (ET_p) using the Jensen-Haise equation modified for local conditions (Jensen and Haise, 1963). Daily crop water use (ET_a) was estimated by multiplying ET_p by crop coefficient (Kc) algorithms for cotton described by Harrison and Tyson (1993). 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 13 mm precipitation would be used as a “carry over” to stop irrigation for a short time span following a precipitation event. Daily ET_a values were subtracted from the “carry over” until its value was zeroed, then irrigation events would resume.

For the Bolton and Newman sites, S3DI and sprinkler systems, irrigation events were scheduled when soil water potential of two sensors (buried 25 and 50 cm) averaged -70 kPa (Sorensen and Lamb, 2019). Soil water sensors and loggers (MPS-2 and EM50R, Decagon, Pullman, WA) were installed after planting about 8 cm off the crop row adjacent the drip laterals. Sensors were interrogated hourly, transmitted to a central location via radio, and downloaded to a laptop computer each morning. When the average of the two sensors reached the required trigger point, irrigation systems were turned on manually. Total water applied was measured using mechanical flow meters. With drip systems, the system could be turned on manually and left unmanned for 18 to 24 h or until the soil water potential sensors registered an irrigation had occurred. For the sprinkler systems, the total water needed to bring the soil sensor measurements back to field capacity (< -15 kPa), could produce runoff from the soil surface. Therefore, sprinkler systems required operation multiple times per day and possibly multiple days to infiltrate enough water to affect the soil sensors.

At the HERC site, irrigation events were scheduled using water potential sensors (Watermark, Irrometer Company, Riverside, CA) installed at 20, 41, and 61 cm soil depth. A cluster of three sensors were installed in each irrigation zone and each crop. Data collected from these watermark sensors were incorporated into IrrigatorPro to determine when and how much to irrigate.

Statistical Analysis. All data were analyzed with the analysis of variance (ANOVA) and all-pair wise multiple comparisons using Statistix 10 (Analytical Software, 2013). ANOVA showed that yield data were significantly different by year and/or location; therefore, each year and location were analyzed separately. Fiber yield along with fiber characteristics were analyzed by row pattern, seeding rate, and row pattern by seeding rate interaction. When ANOVA showed significance, mean separation of row spacing, seeding rate and N level (2003 and 2004, only) and associated interactions were obtained using Tukey's HSD (honest significant difference) pairwise comparison procedure at the p=0.05 level.

RESULTS AND DISCUSSION

The monthly and seasonal total rainfall data by location, year, and month are shown in Table 2. Monthly rainfall data at the Sasser site was not retrievable from the existing database but yearly totals were recorded. Rainfall during 2003 and 2004 were similar at both the Sasser and Shellman locations. During other treatment years, rainfall was variable with 2016 being a dryer year compared with 2017, 2018 and 2019.

Table 2. Monthly rainfall totals by location, month, and year.

Location	Year	May	June	July	Aug.	Sep.	Oct.	Total
		mm						
Sasser	2003	*Monthly values not available*						561.3
	2004	*Monthly values not available*						546.1
HERC	2015	22.9	65.0	127.8	103.6	85.9	17.8	422.9
	2016	48.8	87.9	88.4	40.4	51.1	2.0	318.5
	2017	188.5	126.5	125.5	90.2	108.2	79.5	718.3
	2018	134.4	73.2	153.9	161.5	17.5	180.3	720.9
	2019	64.3	96.5	91.4	128.0	35.6	157.5	573.3
Bolton[z]/ Newman	2015	75.9	43.9	138.4	66.0	90.4	20.1	434.8
	2016	48.0	69.3	52.6	90.4	37.8	0.0	298.2
	2017	121.7	127.3	181.1	153.7	107.7	82.8	774.2
	2018	135.9	71.6	222.3	117.3	26.4	180.1	753.6
	2019	37.8	141.5	78.7	154.9	78.5	168.9	660.4
Shellman	2003	85.1	128.3	149.1	152.4	134.9	31.2	681.0
	2004	34.8	192.0	53.8	118.6	227.1	17.8	644.1
	2015	39.9	34.8	107.2	44.5	120.4	15.7	362.5
	2016	40.6	93.7	72.6	69.3	45.2	0.0	321.6
	2017	108.0	95.3	132.6	73.2	85.1	58.2	552.2
	2018	175.8	50.8	233.4	160.3	59.4	216.7	896.4

[z] **Bolton and Newman farms use the same weather station due to proximity.**

Lint yield and fiber quality characteristics for Sasser and Shellman sites for the 2003 and 2004 crop years are shown in Table 3. Lint yield was greater at the Shellman site compared with the Sasser site. This could be associated with the soil texture since both sites received the same management. There were lint yield differences across years at individual sites. At the Sasser site, the single-row pattern produced greater yield than the twin-row pattern at the same seeding rate. At Shellman, there was no yield difference due to row pattern or seeding rate.

In 2003, fertilizer N application rate impacted yield at the Sasser site, while at the Shellman site, application of 67 kg N/ha resulted in greater yield (1,091 kg/ha) compared with application of 112 kg N/ha (941 kg/ha) (data not shown). In 2004, fertilizer N application treatments showed that the 112 kg N/ha rate resulted in greater yield at both the Sasser and Shellman sites (1,008 versus 817 kg/ha, respectively, data not shown). Across both years, lint yield was greater following application of greater fertilizer N rates at the Sasser site but not at the Shellman site. This could be explained by the soil texture as described above (Table 3).

These data do not give enough evidence to recommend exclusively either 67 or 112 kg N/ha for increased yield. These findings are consistent with those of Bauer et al. (1997) and Sorensen et al. (2006) where yields were not increased with fertilizer N application rate, timing, or irrigation system (SSDI). It can be concluded that a N rate between 67 and 112 kg N/ha is valid with SSDI for cotton yields and is similar to N values currently recommended (Georgia cotton production guide, 2018). In all research after the 2003 to 2004 growing season, an average of 90 kg N/ha was used which is similar to local recommendations (Georgia cotton production guide, 2018) for 1,075 kg/ha yield goal. At both Sasser and Shellman (2003 and 2004), it was concluded that row pattern had no impact on yield, and that either single- or twin-row planting is a viable option. It can also be concluded that a N rate between 67 and 112 kg N/ha is valid and is similar to values currently recommend (Georgia cotton production guide, 2018). Fiber quality characteristics were different due to year, row pattern, or N rate. However, none of the values were consistent across treatments to draw any conclusion and would not have caused value deductions to decrease economic income.

Table 3. Cotton lint yield and grade characteristics by location, year, row pattern, and nitrogen level for 2003 and 2004.

Treatment	Lint Yield -- kg/ha --	Micronaire	Length --- mm ---	Strength --- g/tex ---	Uniformity ---- % ----
Sasser					
Year					
2003	**788a[z]**	**4.4a**	**28.1a**	**29.3a**	**82.1a**
2004	**717b**	**4.4a**	**28.0a**	**29.0a**	**81.7b**
Row Pattern[y]					
S1	**820a**	**4.7a**	**27.9b**	**29.0a**	**81.7a**
T1	**701b**	**4.4b**	**28.3a**	**29.4a**	**82.1a**
Nitrogen					
67	**705b**	**4.6a**	**28.1a**	**29.1a**	**81.9a**
112	**800a**	**4.3b**	**28.0a**	**29.2a**	**81.9a**
Shellman					
Year					
2003	**1,014b**	**3.6b**	**28.4b**	**28.2b**	**82.0a**
2004	**1,166a**	**3.9a**	**29.1a**	**31.5a**	**81.5b**
Row Pattern					
S1	**1,167a**	**3.7a**	**28.9a**	**30.0a**	**81.8a**
T1	**1,058a**	**3.8a**	**28.7a**	**29.6a**	**81.7a**
Nitrogen					
67	**1,047a**	**3.9a**	**28.6a**	**29.7a**	**81.6a**
112	**1,133a**	**3.6b**	**28.9a**	**30.1a**	**81.9a**

[z] **Different letters following values within a column and treatment are significant using Tukey Honest Significant Difference pairwise comparison at the p≤0.05 level.**

[y] **S1 = single row, T1=twin row.**

Lint yield and fiber characteristic probability values by location, year, and irrigation system are shown in Table 4. Cotton yield when grown on single- versus twin-row pattern was only significant in two out of the 13 test years, locations, or irrigation system treatments. Cotton yield was significantly different in 2003 and 2019 at the Sasser and Newman site, respectively. At both sites, the single-row configuration produced greater yield compared to the twin-row pattern, ranging from 161 (Sasser) to 269 kg/ha (Newman).

There was no lint yield decrease when the 0.5X seeding rate was compared with the 1X seeding rate (Table 4). Final plant stand for cotton across years, locations, and row pattern treatments were 52,318 and 84,918 plants/ha for the 0.5X and 1X seeding rate, respectively. Thus, the final 0.5X plant population was about 38%of the 1X plant population. Though the 50% plant population was not totally achieved, the reduction in total seed planted could save the grower in seed costs. This implies that a seeding rate of about 5 seeds/m (54,600 seeds/ha) may be recommended for either single or twin row even though it is at the lower end of the seed rates recommended in Georgia. With planter inaccuracies, seedling death, or other emergence problems, a final plant stand of 4.5 plants/m (about 49,100 plants/ha) may produce adequate yield. A final plant population of 49,100 plants/ha was greater than the threshold of 35,000 plants/ha described by Adams et al. (2019) for dramatic loss of cotton yield in the arid Texas regions. This implies that plant populations at the 0.5X may be cost effective for reducing seed costs while maintaining an adequate yield.

Table 4. Lint yield and fiber characteristics probability values by location, year, and irrigation system, for treatments of row spacing, seeding rate, and row spacing by seeding rate interaction.

Location	Year	Irrigation System[z]	Treatment[y]	Lint Yield	Fiber Characteristics			
					Length	Strength	Micronaire	Uniformity
				Probability Values				
Bolton	2016	Sprinkler	Row	0.262[x]	0.034	0.428	0.661	0.359
			Seed	0.262	0.538	0.474	0.522	0.231
			R x S	0.165	0.390	0.250	0.953	0.848
	2017	Sprinkler	Row	0.135	0.782	0.984	0.232	0.589
			Seed	0.584	0.124	0.222	0.232	0.104
			R x S	0.140	0.416	0.520	0.460	0.309
HERC	2019	Sprinkler	Row	0.526	0.548	0.390	0.169	0.418
			Seed	0.347	0.548	0.224	0.721	0.906
			R x S	0.201	0.372	1.000	0.025	0.613
Newman	2016	S3DI	Row	0.359	0.382	0.756	0.716	0.272
			Seed	0.589	0.048	0.900	0.027	0.311
			R x S	0.735	0.310	0.319	0.771	0.973
	2017	S3DI	Row	0.260	0.157	0.047	0.923	0.600
			Seed	0.290	0.079	0.005	0.048	0.027
			R x S	0.208	0.701	0.070	0.078	0.340
	2019	S3DI	Row	0.002	0.888	0.773	0.031	0.513
			Seed	0.137	0.341	0.041	0.056	0.002
			R x S	0.683	0.676	0.489	0.721	0.162
Sasser	2003	SSDI	Row	0.009	0.007	0.001	0.011	0.001
	2004	SSDI	Row	0.433	0.773	0.880	0.038	1.000
Shellman	2003	SSDI	Row	0.152	0.628	0.584	0.765	0.282
	2004	SSDI	Row	0.430	0.354	0.503	0.222	0.591
	2016	SSDI	Row	0.715	0.613	0.797	0.264	0.858
			Seed	0.796	0.203	0.510	0.070	0.601
			R x S	0.196	0.978	0.197	0.474	0.975
	2017	SSDI	Row	0.995	0.905	0.220	0.952	0.719
			Seed	0.946	0.968	0.482	0.812	0.406
			R x S	0.810	0.232	0.032	0.350	0.719
	2017	S3DI	Row	1.000	0.876	0.600	0.478	0.785
			Seed	0.476	0.876	0.264	0.297	0.694
			R x S	0.665	0.187	0.193	0.175	0.360

[z] Irrigation systems are subsurface drip irrigation=SSDI; shallow subsurface drip irrigation=S3DI; and overhead sprinkler irrigation=Sprinkler.

[y] Row=row spacing; Seed= seeding rate; R x S = row spacing by seeding rate interaction.

[x] Probability values are significant at $p \leq 0.05$.

There was no row spacing by seeding rate interaction effect on lint yield. There were some differences across years, locations, and irrigation systems for fiber length, strength, micronaire, and uniformity. However, there was no consistency in any of these characteristics to be able to draw any conclusions across treatments for any of the fiber characteristics measured. Any significant difference in fiber characteristic values due to treatments were not great enough to cause any economic deductions to the lint value. These findings are compatible with those of Balkcom et al. (2010), Boykin and Reddy (2010), and Stephenson et al. (2011) who showed that row pattern, either single- or twin-row, had little effect on lint yield. Also, that seeding rate was not necessarily a factor on lint yield, provided seed population was not extreme from the recommended values.

Average cotton lint yield across locations, years, and irrigation systems are shown in Table 5. Yield values were not different within years or locations due to either row pattern or seeding rate, except at Sasser in 2003 (Table 4). Across all locations and years, the single-row pattern produced an average yield of 1,337 kg/ha versus 1,253 kg/ha for the twin-row pattern. The 1X seed rate produced a lint yield of 1,438 kg/ha versus 1,391 kg/ha for the 0.5X rate. A direct comparison of irrigation systems was not statistically valid as irrigation systems were not installed at the same time in all fields or years. In general, cotton lint yields when grown under sprinkler irrigation varied widely especially at the Bolton farm. Cotton grown using the S3DI system at Newman farm averaged 1,303 kg/ha when seeded at the 1X rate and 1,235 kg/ha when seeded at the 0.5X rate. These values for Newman are similar for the average S3DI system at the Shellman farm at 1,409 and 1,317 kg/ha for the 1X and 0.5X seeding rate, respectively. Overall, from a yield perspective, there does not seem to be a recommended irrigation system for greater lint yield.

The expense to plant at the 1X seeding rate was about $228/ha while the 0.5X rate was $141/ha (https://agecon.uga.edu/extension/budgets.html – 2020 irrigated cotton); a savings of $87/ha in seed cost or about 65 kg/ha of lint with lint values at $1.32/kg. In three out of the nine site years tested (33%), the reduced seed cost for the 0.5X seeding rate did not cover the loss of revenue from reduced yield. Therefore, reduced seeding rate may have a seed cost savings but may not always cover the possible loss of revenue from the lower yield even when the yields are not statistically different from a normal seeding rate.

Table 5. Lint yield values by location, year, and irrigation system for row spacing and seeding rate (1X = 93,000 seeds/ha, 0.5X = 53,000 seeds/ha).

Location	Year	Irrigation System	Row Pattern		Seeding Rate	
			Single	Twin	1X	0.5X
			kg/ha			
Bolton	2016	Sprinkler[z]	1,075a[y]	1,145a	1,145A	1,075A
Bolton	2017	Sprinkler	538a	414a	452A	489A
HERC	2019	Sprinkler	1,624a	1,586a	1,634A	1,575A
Newman	2016	S3DI	1,511a	1,457a	1,500A	1,468A
Newman	2017	S3DI	1,172a	1,102a	1,167A	1,102A
Newman	2019	S3DI	1,339a	1,038b	1,242A	1,134A
Shellman	2016	SSDI	1,688a	1,650a	1,656A	1,683A
Shellman	2017	SSDI	1,446a	1,446a	1,446A	1,441A
Shellman	2017	S3DI	1,360a	1,360a	1,409A	1,317A

[z] SSDI=subsurface drip irrigation; S3SDI=shallow subsurface drip irrigation; sprinkler=overhead sprinkler irrigation.

[y] Values in the same row with either lower- (row pattern) or upper-case (seeding rate) letters are not significant at the p≤0.05 level.

CONCLUSIONS

Cotton yield when grown on single- versus twin-row pattern was only significant in two out of the 13 test years, locations, or irrigation system treatments. There was no lint yield decrease with the 0.5X seeding rate compared with the 1X seeding rate. There was no yield effect due to a row spacing by seeding rate interaction. There were some differences across years, locations, and irrigation systems for fiber length, strength, micronaire, and uniformity. However, there was no consistency in any of these grade characteristics across treatments to be able to draw any conclusions for the fiber characteristics measured. Any significant difference in values due to treatments were not great enough to cause any economic deductions to the lint value. Overall, planting with either single- or twin-rows does not affect yield. Also, the use of drip or sprinkler systems does not seem to affect yield. The decision to plant at a lower seeding rate may have a seed cost savings but may not always cover the possible loss of yield and associated revenue that may occur.

DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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