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ENGINEERING AND GINNING

Influence of Seeding Rate, Planter Downforce and Cultivar on Crop Emergence and Yield in Singulated and Hill-Dropped Cotton

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ABSTRACT

Cotton (Gossypium hirsutum L.) growers are motivated to reduce seeding rates due to increased technology fees associated with improved transgenic cotton cultivars. Advances in planting machinery have improved precision of seed metering and seed placement in recent years. A two-year study was conducted to evaluate the effect of seeding rate, planter downforce, and cultivar on crop emergence and lint yield in cotton planted as singulated and hill-drop (two seed hill^{-1}) configuration. Study treatments consisted of two seeding rates (71,660 and 107,490 seed ha^{-1}), two to three planter downforces (0, 445 and 890 N in 2017; 0 and 890 N in 2018) and two cotton cultivars (representing a large-seeded and small-seeded cultivar, 9,259 - 10,582 and 11,244 - 14,330 seed kg^{-1}, respectively) arranged in a strip-split plot design in both seeding configurations. Crop emergence and lint yield in the middle two rows (four-row plots) were measured to evaluate treatment effects among seeding configurations. Results showed that seeding rate and cultivar did not affect ($p>0.05$) crop emergence and lint yield in both singulated and hill-drop cotton. Crop emergence varied between the two years due to differences in field tillage conditions. Planter downforce affected crop emergence in singulated cotton but not in hill-drop cotton during both years. Field tillage conditions also influenced downforce effect on crop emergence. Selection of an optimal planter downforce had more significant effect ($p<0.05$) on singulated cotton than hill-dropped cotton. Results showed that large-seeded cultivars can be utilized to attain a high crop emergence early in the season which can help in minimizing production risks associated with poor stand establishment. High seed and technology fees incurred by growers can be effectively reduced by planting lower seeding rates - given an adequate stand establishment is attained using appropriate planter setup including downforce and cultivar selection.

Higher seed costs due to technology fees associated with transgenic cotton cultivars have increased input costs for growers. Further, low market prices and expensive machinery involved in cotton production have reduced profit margins and motivated growers to reduce input costs by being more efficient with crop inputs required to maximize returns. To provide up-to-date information to growers, recent research efforts have been focused on how to properly utilize agronomic knowledge with improvements in planting and seed technology to enable better management of crop inputs while sustaining higher crop yields. Past research suggests that early and rapid emergence of cotton plants maximizes yield potential (Wanjura et al., 1969; Wanjura, 1977), whereas delayed emergence can reduce plant population and impact yield (Wanjura, 1982). Numerous population studies have been conducted on cotton to determine the optimal plant population for maximum yields; however, the optimal plant population varies with production environment including location, weather, cultivar and grower preference (Lane, 1956; Silvertooth et al., 1999). Peebles et al. (1956) reported plant populations with plant spacing of 5.1 to 15.2 cm (2 to 6 inches) yielded more than populations with 30.5 to 40.6 cm (12 to 16 inches) plant spacing in upland cotton. A plant population of 74,131 plants ha^{-1} produced the highest yield as reported by Douglas et al. (1964) in a three-year study in Georgia with plant

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populations ranging from 24,710 to 222,395 plants ha^{-1}. Duncun and Pete (1964) measured cotton lint yield for a wide range of plant populations (16,139 to 64,556 plants ha^{-1}) and reported plant populations of less than 32,278 plants ha^{-1} reduced yields. Other similar research studies have also observed reduced yields at low populations in the range of 33,969 to 44, 444 plants ha^{-1} or high plant populations ranging from 118,000 to 144,495 plants ha^{-1} (Hawkins and Peacock, 1971; Bridge et al., 1973; Smith et al., 1979; Ali et al., 2010). Several other researchers, however, have reported no differences in lint yield for a wide range of plant populations: 35,197 – 271,815 plants ha^{-1} (Ray et al., 1959); 214,977 – 358,295 plants ha^{-1} (Baker, 1976); 64,247 – 130,965 plants ha^{-1} (Franklin et al., 2000); and 45,015 – 230,082 plants ha^{-1} (Bednarz et al., 2000).

Various population studies with different hill-spacing have also been conducted to evaluate the effect of additional seed on cotton yield and determine optimal within-hill population. Leding and Lytton (1934) suggested planting one or two plants at 30.5 cm (12 inch) intervals for the highest yield with two plants being more desirable. Hawkins and Peacock (1970) also noticed the highest yield for cotton planted at one plant per hill spaced 30.5 cm apart. The study compared one, two and six plants per hill spaced at 30.5 and 60.1 cm (12 and 24 inches) apart with plant populations in the range of 16,061 to 192,742 seed ha^{-1}. Colwick (1965) reported comparable yields for both singulated (drilled) and hill-drop planted cotton for the same plant populations whereas Tavernetti and Ewing (1957) observed a lower yield for hill-drop planted cotton when compared to singulated cotton at the same plant populations. In a study conducted by Hawkins and Peacock (1972) in Georgia, lint yield varied significantly for different within-row spacings but was not affected by number of plants per hill. Siebert et al. (2006) evaluated cotton lint yield at various plant densities and seeding configurations in an effort to determine an optimal seeding combination that minimizes seed use without sacrificing yield. No significant differences in lint yield between singulated and hill-drop (3 seed hill^{-1}) configuration were observed at the same plant population; however, yield was reduced at 60 cm hill spacing in hill-drop configuration compared to hill spacing of 20 and 40 cm.

Optimal planter setup including depth and downforce is important to achieve desired seed placement performance during planting. Downforce is the supplemental load applied additional to the weight of the row-unit itself and is mostly shared by double-disc openers and gauge wheels on row-crop planters (Brune et al., 2018). Adequate planter downforce (additional force applied to a row-unit above its weight to achieve desired seeding depth) selection has been suggested as an important consideration by several researchers (Hanna, et al., 2010; Virk et al. 2020; Sharda et al., 2016; Poncet et al., 2018) when trying to attain uniform seeding depth and adequate stand establishment, especially when planting in varying field conditions. Lack of adequate downforce can result in seed depth variations across the field as seed placed shallower or deeper than the desired seeding depth can exhibit emergence issues and can potentially affect crop yield (Thomison et al., 2012). Besides ensuring proper planter setup including depth and downforce, cultivar selection is an important decision that growers undertake at the beginning of the growing season. Cotton seed size is strongly correlated to seedling vigor (Snider et al., 2016; Virk et al., 2019). Large-seeded cultivars tend to perform better by exhibiting higher seedling survival, emergence uniformity, and seedling growth than small-seeded cultivars (Reis and Everson, 1973; Roy et al., 1996; Ankaiah et al., 2013). Due to these characteristics, large-seeded cultivars with vigorous growth are generally recommended to establish adequate plant stand in challenging early-season production environments.

Many growers across the United States (US) plant hill-drop cotton to combat emergence problems and ensure adequate stand establishment in crusted soils. In Georgia, the current seeding rate recommendations for hill-drop cotton is two seed every 20 to 25 cm (86,110 – 107,490 seed ha^{-1}) while a seeding rate of at least two seed every 30 cm (71,660 seed ha^{-1} or higher) is recommended for planting singulated cotton to attain adequate stand establishment and achieve maximum yields (UGACE, 2019). The general trend among growers in Georgia is to plant two to three seed every 30 cm (71,660 – 107, 490 seed ha^{-1}) for singulated cotton whereas the hill-drop cotton is mostly planted at two seed every 25 cm (107,490 seed ha^{-1}; two seed hill^{-1}) to ensure an acceptable stand in crusted soil conditions. A comparative study by Siebert et al. (2006) reported no yield differences in singulated and hill-drop cotton among populations of 50,958, 76,466 and 152,883 seed ha^{-1}, however the authors only included three seed per hill configuration in hill-drop cotton. In addition, the study was limited to a production environment representing non-irrigated silt loam soil during both years. The majority of the cotton production in Georgia occurs in southern coastal plain soils dominated by Tifton loamy sand and more than fifty percent of the cotton grown in Georgia is irrigated via center or lateral irrigation systems. Recent research efforts on evaluating seeding rates in either seeding configuration (singulated or hill-drop) in local cotton production environment in Georgia are limited.

With increasing seed and technology fees in recent years, Georgia growers are interested in knowing if hill-drop seeding rates can be lowered from their nominal seeding rate of two seed every 25 cm (107,490 seed ha^{-1}) without incurring any significant yield penalties. Several past researchers have concluded that uniform seed placement is more critical for timely emergence and maximizing yield potential than seeding rate (Lee, 1968; Wanjura, 1980). Advancements in planting machinery over the years have improved seed metering and seed placement capabilities leading to high seed singulation and seed spacing performance in the field. Previous researchers evaluated various plant populations in different seeding configurations with little or no consideration to other planting variables that can affect crop emergence or yield in singulated and hill-drop cotton. The availability of advanced planting machinery and new transgenic cotton cultivars, motivates growers to identify any potential management variations (machinery and agronomic) that could maximize crop emergence and yield potential in cotton. The main objective of this study was to evaluate the effects of seeding rate, planter downforce and cultivar (seed size) on crop emergence and yield in both singulated and hill-drop planted cotton.

METHODS AND MATERIALS

Research experiments were conducted at the University of Georgia, Gibbs Research Farm (31.436242N, -83.580044W) and Plant Sciences Farm (31.483840N, -83.522006W located in Tifton (Tifton, GA) during the 2017 and 2018 growing seasons, respectively. The predominant soil type on both research farms (including research sites) is Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Both research sites were irrigated land and received an average rainfall of 79 and 91 cm during the growing season (May through November) in 2017 and 2018, respectively. Study treatments consisted of a factorial arrangement of seeding configuration, cultivar, planter downforce and seeding rate arranged in a split-strip plot design where seeding configuration and cultivar were treated as whole plots, and combinations of planter downforce and seeding rate served as subplots. Seeding configuration was implemented in strips across the field whereas both cultivars were arranged adjacent to each other and blocked within each seeding configuration. Planter downforce and seeding rate combinations were randomized within each seeding configuration. Each treatment combination was assigned to plots that measured 3.66 m wide (four planter rows) and 10.67 m long, replicated four times.

Table 1. Levels of downforce, seeding rate and cultivar treatments implemented in the singulated and hill-dropped cotton in 2017 and 2018

Treatments	Levels	
	2017	2018
Seeding Rate (seed ha^{-1})	71,660	71,660
	107,490	107,490
Downforce (N)	0	0
	445	.
	890	890
Cultivar	PHY 312	PHY 312
	DP 1553	DP 1555

Table 1 provides information on downforce, seeding rate, and cultivar treatments used in studies conducted in 2017 and 2018. The selected seeding rates and planter downforce values represented nominal seeding rates (71,660 and 107,490 seed ha^{-1} for singulated, and 107,490 seed ha^{-1} for hill-drop) and downforces (0, 445, and 890 N) typically utilized by growers in Georgia. The seeding rates were also based on University of Georgia Cooperative Extension recommendations for planting cotton (UGACE, 2019) while the selected downforces are among the standard options available on planters equipped with mechanical downforce system. In 2017, statistical analysis showed no crop or yield differences between 445 and 890 N downforce, therefore a level of downforce (445 N) was eliminated from the 2018 study. Each year, cotton cultivars differing in seed size were acquired from commercial seed companies. PHY 312 represented a large-seeded cultivar (9,259 – 10,582 seed kg-1) during both years whereas DP 1553 and DP 1555 (11,244 – 12,346 seed kg-1 and 12,566 – 14,330 seed kg-1, respectively) represented a small-seeded cultivar in 2017 and 2018, respectively. The selected cultivars were among the most commonly planted cultivars by growers across the state of Georgia in these two years. For planting cotton, each treatment combination was planted in both seeding configurations: singulated and hill-drop. For these studies, planting single seed spaced evenly within the row is referred to as singulated cotton whereas two seed planted together (two seed per hill) at each location within the row is referred to as hill-dropped cotton. In both seeding configurations, cotton was planted at the same seeding rate (seed per hectare) while the number of seed per hill (single seed – singulated and two seed – hill-drop) and within-row seed spacing varied in each seeding configuration. Table 2 presents information on different within-row hill spacings obtained in both singulated and hill-drop cotton for seeding rates of 71,660, and 107,490 seed ha^{-1}. It can be noted that at a given seeding rate, the seed spacing in hill-dropped cotton (two seed per hill) was double the seed spacing in singulated cotton.

Table 2. Within-row seed spacing at the seeding rates for singulated and hill-drop seeding configurations

Seeding Rate (seed ha^{-1})	Within-row Seed Spacing (cm^z)	
	Singulated	Hill-drop^y
71,660	15	30
107,490	10	20

^{z} values rounded to the nearest ten

^{y} seed spacing for two seed per hill

Planting Equipment. Cotton was planted using a four-row Monosem NG *Plus4* vacuum precision planter (Monosem Inc., Edwardsville, KS) (Figure 1a) equipped with vacuum seed meters and a commercially available spring-based mechanical downforce system. Target seeding rates were achieved by selecting the appropriate gear ratio for the ground wheel drive and main shaft driving the seed meters as recommended in the operator's manual provided by the equipment manufacturer. Singulated and hill-drop seeding configurations were attained by utilizing a 24-cell single seed disc (Part# DN3635, Monosem Inc., Edwardsville, KS) and a 12-cell hill-drop seed disc (Part# DN1230D, Monosem Inc., Edwardsville, KS), respectively.

The commercially available downforce system on the planter is comprised of heavy-duty springs mounted to parallel linkages on each row-unit to exert additional load in excess of the row-unit weight on the gauge-wheels (Monosem Up/Down Pressure Assembly, Model# KA2068Q, Monosem Inc., Edwardsville, KS). Downforce adjustments were made by positioning the spring-loaded arm in two different positions (out of four) which changes the spring tension, thus varying the amount of load applied on gauge-wheels (downforce adjustments 1-4 shown in the diagram in Figure 1b). The selected positions of the arm corresponded to approximately 445 and 890 N of applied force (Monosem NG +4 7x7 Mounted Single Row Planter Manual, Monosem Inc., Edwardsville, KS) on individual row-unit whereas disengaging the arm resulted in no additional load (0 N) on the row-unit beside its own weight. Each planter row-unit had a pair of backward curved row cleaners (Yetter SharkTooth® Wheel, Model# 2967-602, Yetter Manufacturing Co., Colhester, IL) in front of the furrow openers for residue management in strip-till planting conditions, and a pair of twin offset discs followed by a flat press wheel (Monosem Disc Closing Flat Wheel, Model#900083, Monosem Inc., Edwardsville, KS) centered behind the double-disc openers as a furrow closing mechanism. In 2017, cotton was planted following conventional tillage in the field whereas cotton was planted in strip-till conditions with partial wheat residue on the soil surface in 2018. Cotton was planted at a seeding depth of 2.5 cm and a row spacing of 91.4 cm during both years. Research trials were planted on May 16th in 2017 and May 3rd in 2018, and were maintained using standard cultural practices during the growing season as per University of Georgia Cooperative Extension recommendations (UGACE, 2019).

(a) (b)

Figure 1. (a) Four-row Monosem NGPlus vacuum precision planter, and (b) mechanical downforce system (shown in dashed box and diagram). Figure shows system in disengaged position.

Data Collection and Analysis. To assess plant population, stand counts were performed at three weeks after planting when all emergence had occurred in each plot. Within each plot, number of emerged cotton plants in 3.1 m long randomly selected section were counted in the center two rows. Plant population in plants per hectare were calculated from the stand counts performed in each plot. Further, crop emergence (in percent) was computed by dividing plant population by the target seeding rate applied within each plot to standardize population data and enable comparison among different study treatments. Since it is difficult to accurately measure actual planted seed depth in cotton due to high possibility of displacing the seed from its original position while digging, seed depth measurements were not performed during data collection. The downforce effect in cotton was evaluated based on percent crop emergence as past research suggests that seed depth variations due to inadequate downforce usually results in delayed or uneven emergence. Yield data was collected by harvesting the center two rows in each plot using a two-row spindle picker. Cotton samples were ginned at the University of Georgia's microgin located in Tifton, GA to determine lint weight for each plot. Lint yield was determined by dividing lint weight (wet basis) by harvested area (two 0.9 m rows wide and 10.67 m long) of each plot. Similar data collection and harvest protocols were followed during 2017 and 2018. It should be noted that a tropical storm with wind speeds up to 50 mph and excessive rainfall affected cotton plants in southern part of the State during mid-September resulting in reduced yields during 2017. The University of Georgia extension cotton agronomists and economists estimated this yield loss to be around 30-40% in most fields in the Southwest region. In 2017 study, yield losses at the research site were assumed to be constant across all the study treatments during data analysis and for discussion of yield results. Yield losses were not calculated separately for each cultivar and assumed to be constant for both the cultivars used in these studies.

Due to differences in tillage and weather conditions between the years, data for each year was analyzed separately. Considering the strip-split plot design, data was subjected to analysis of variance using default PROC GLM procedure in SAS 9.4 (SAS Institute Inc., Cary, NC) with corrected error terms for fixed and random effects. For analysis of variance, the main effects of seeding configuration, seeding rate, downforce, cultivar and all interactions among them were used as fixed effects in the model whereas rep, rep x seeding configuration, rep x cultivar and rep x seeding configuration x cultivar were considered random effects. Special SAS statements such as h = seeding configuration, e = rep x seeding configuration were used to calculate appropriate error terms for testing significance of random effects. To perform multiple comparisons of means using a standardized t-test procedure, MEANS LSD option was used in PROC GLM procedure during analysis of variance in SAS 9.4. A default alpha value of 0.05 ($p<0.05$) was used for comparison among treatment means during statistical analysis.

RESULTS AND DISCUSSION

Results from analysis of variance for the main and interaction effects of seeding configuration, seeding rate, downforce and cultivar on crop emergence and lint yield are presented in Table 3. Since these studies were aimed at evaluating the effect of seeding rate, downforce and cultivar on crop emergence and lint yield between the two seeding configurations (singulated and hill-drop), the interaction effects of interest here were seeding configuration x seeding rate (SC x SR), seeding configuration x downforce (SC x DF) and seeding configuration x cultivar (SC x CV). All other second and higher order interactions were insignificant for both crop emergence and lint yield at the selected significance level of $p \leq 0.05$ during 2017 and 2018, hence they are not discussed further in the results presented here. Detailed results and discussion on significance of individual main effects (SR, DF and CV) and their interaction with seeding configuration are presented in the subsequent sections.

Table 3. Observed significance levels for crop emergence and lint yield to seeding configuration, seeding rate, downforce and cultivar in 2017 and 2018

Source of Variance	Emergence ($p > F$)		Yield ($p > F$)	
	2017	2018	2017	2018
Seeding Configuration (SC)	0.1222	0.8910	0.0906	0.8347
Seeding Rate (SR)	0.0156*	0.2206	0.0154*	0.1001
Downforce (DF)	0.0063*	0.0488*	0.8768	0.2705
Cultivar (CV)	0.0377*	0.0114*	0.4214	0.0901
SC x SR	0.2327	0.1407	0.8956	0.6698
SC x DF	0.0168*	0.0426*	0.6822	0.3488
SC x CV	0.2327	0.8442	0.4599	0.6922
SR x DF	0.1299	0.8770	0.9501	0.9458
SR x CV	0.0534	0.9803	0.9161	0.2270
DF x CV	0.9385	0.7150	0.8574	0.3505
Other interaction terms	NS[z]	NS	NS	NS

[*] indicates effect significant at $p<0.05$.

[z] NS represents non-significant at $p<0.05$

Seeding Rate. The SC x SR interaction was not significant ($p>0.05$) for crop emergence or yield in 2017 and 2018 (Table 3). This indicates that crop emergence and cotton yield did not vary significantly between the two seeding configurations for both seeding rates. In 2017, seeding rate was significant for crop emergence ($p=0.0156$) and yield ($p=0.0154$) but it had no effect on crop emergence ($p=0.2206$) and yield ($p=0.1001$) in 2018. Mean crop emergence (approx. 50% – 70%) was lower in 2018 than mean emergence (approx. 70% – 87%) attained in 2017. This was attributed to difference in tillage conditions between the two years. Past research studies have also reported decreased emergence due to potential stand establishment issues in conservation tillage systems (Brown et al., 1985; Burmester et al., 1993). Emergence problems in conservation tillage systems have also been linked to poor seed placement performance (seed depth and seed-to-soil contact) of planting equipment due to large amounts of crop residue and increased soil resistance (Erbach et al., 1983; Grisso et al., 1984; Morrison and Gerik, 1985). In singulated cotton, no emergence differences were observed among the seeding rates in 2017 and 2018 (Table 4). For hill-drop cotton, the lower seeding rate of 71,660 seed ha^{-1} exhibited greater crop emergence than 107,490 seed ha^{-1} rate in 2017. In 2018, the crop emergence varied by more than 10% between the 71,660 and 107,490 seed ha^{-1} rates in hill-drop cotton, however emergence was not significantly different among the seeding rates.

For yield response to seeding rate, lint yield was highest at 107,490 seed ha^{-1} seeding rate in both seeding configurations (Table 4). In both years, lint yield was not significantly different among seeding rates in both singulated and hill-drop cotton. Our study results indicated that similar yields can be obtained with seeding rates of 71,660 and 107,490 seed ha^{-1} if planted as singulated or hill-drop configuration. Similar study conducted by Harrison et al. (2009) reported no yield differences for cotton seeding rates of 96,371 and 128,494 plants ha^{-1} planted as both singulated and hill-drop (two seed $hill^{-1}$) seeding configuration. The authors reported that given soil and environmental conditions are optimal, and a good-quality seed is available, cotton seeding rates can be lowered from 128,494 seed ha^{-1} to 96,371 seed ha^{-1} (in both singulated and hill-drop). Results from our study indicates that cotton seeding rates can be lowered from 107,490 seed ha^{-1} to 71,660 seed ha^{-1} without occurring an impact on yield given an adequate stand is achieved.

Many past studies in cotton to determine optimal population for maximum yields have evaluated different plant populations (obtained by over-seeding and thinning) than seeding rate per se., so it would also be useful to look at plant populations (established stand) attained in our study with results from previous studies. In 2017, the seeding rate of 71,660 and 107,490 seed ha^{-1} resulted in average plant population of 58,331 and 84,057 plants ha^{-1} in singulated cotton, and 61,556 and 86,637 plants ha^{-1} in hill-drop cotton. In 2018, the seeding rate of 71,660 and 107,490 seed ha^{-1} resulted in average plant population of 41,990 and 64,171 plants ha^{-1} in singulated cotton, and 45,791 and 55,895 plants ha^{-1} in hill-drop cotton. Results indicated that no lint yield differences existed for plant populations in the range of 58,331 to 86,637 plants ha^{-1} in 2017 and from 41,993 to 64,171 plants ha^{-1} in 2018 regardless of seeding configuration. The plant population range obtained in our study was quite narrow compared to a broad range achieved by other researchers as we only tested two different seeding rates. Seibert et al. (2006) reported similar lint yields across the populations of 33,975 seed ha^{-1} to 152,883 seed ha^{-1} in both singulated and hill-drop cotton (three seed $hill^{-1}$). Other studies by Bridge et al. (1973), Bednarz et al. (2000), and (Franklin et al., 2000) also showed no differences in yield for a wide range of plant populations (70,000 – 121,000 plants ha^{-1}, 38,623 – 276,983 plants ha^{-1}, and 64,231 – 129111 plants ha^{-1}, respectively). Most studies have reported that the final yield in cotton is relatively stable across wide range of population densities and attributed this yield stability to cotton's ability to compensate for varying within-row spacings and plant populations. Yield stability across different populations is attributed to increase in number of bolls per plant at lower densities (Siebert et al., 2006) and fewer bolls and lost seed cotton per plant at higher populations (Bednarz et al., 2000).

Table 4. Influence of seeding rate on crop emergence and lint yield in singulated and hill-dropped cotton in 2017 and 2018

Seeding Configuration	Seeding Rate (seed ha^{-1})	Emergence (%)		Lint Yield (kg ha^{-1})	
		2017	2018	2017	2018
Singulated	71,660	81.4ab^{z}	58.6a	895b	1470a
	107,490	78.2b	59.7a	1017ab	1656a
Hill-drop	71,660	85.9a	63.9a	975ab	1515a
	107,490	80.6b	52.0a	1109a	1626a

^{z} means followed by the same letter within each column are not significantly different from each other at p<0.05.

Downforce. The seeding configuration x downforce interaction was significant (p=0.0168) for crop emergence in 2017 and 2018 but non-significant for lint yield during both years (Table 3). When cotton was planted using 890 N downforce, crop emergence varied significantly between singulated and hill-drop seeding configuration (Table 5). In singulated cotton, crop emergence was reduced when a planter downforce of 445 and 890 N was used for planting cotton in 2017. An opposing trend was observed in 2018 where singulated cotton exhibited higher emergence at 890 N of downforce than treatments where no additional downforce (0 N) was utilized. The results attained here were primarily due to the difference in tillage conditions between the two years. Field conditions in 2017 represented conventional tillage while 2018 field conditions represented strip-till conditions. These results were expected as optimal planter downforce varies by field condition (soil texture, tillage, moisture etc.) and inadequate planter downforce can result in delayed or reduced emergence (Hanna et al., 2010; Sharda et al., 2016; Virk et al., 2020). Generally, a low downforce is required to plant in well prepared field conditions in conventional planting—in most cases the weight of the planter row-unit is sufficient to achieve the desired seed depth as observed in the results attained in 2017 study. On the contrary, strip- or no-till planting conditions usually requires a high downforce due to increased soil resistance and presence of crop residue on the soil surface (Bowen, 1966; Erbach et al., 1983). While a similar downforce effect on crop emergence can be expected in hill-dropped cotton, the emergence was quite similar across different downforce levels in both years. These results suggested that crop emergence in singulated cotton was affected by planter downforce whereas this effect was not observed in the hill-dropped cotton. This can be explained by hill-dropped cotton having multiple plants pushing through the soil crust compared to a single cotton seedling which is comparatively weak to overcome the soil compaction caused by excessive downforce.

During both years, no effect of planter downforce on lint yield was noticed among seeding configurations (Table 5). Despite reduced emergence at higher downforce (445–890 N in singulated cotton in 2017, similar lint yields (946–972 kg ha^{-1}) were attained across different downforce levels. Similarly, lint yields were not statistically different (p>0.05) between 0 and 890 N downforce in 2018 in singulated cotton regardless of decreased crop emergence at the lowest downforce (0 N). This was attributed to high variations (340–380 kg ha^{-1}) in lint yield among planter downforces in singulated cotton in 2018. Comparable lint yield despite reduced emergence for some downforce treatments can be attributed to cotton's indeterminate nature and ability to compensate for stand loss or uneven stand establishment in different field conditions. The yield stability across a range of population densities is achieved through manipulation of boll occurrence and weight (Bednarz et al., 2000). In our study, lint yield was also similar across different levels of downforce in hill-dropped cotton in both years. Previous research on investigating the effect of planter downforce on crop yield has been limited to corn - where reduced yields at higher downforce has been reported by some researchers (Poncet et al., 2018) and similar yields across different downforce levels by other researchers (Hanna et al., 2010). Though planter downforce selection did not influence cotton yield, crop emergence results showed that an optimal downforce selection, especially in singulated cotton, can help in higher establishment which is important to minimize other in-season production risks and maximize crop yield potential early in the season. Utilizing an adequate planter downforce maintains a consistent and uniform seed depth across the field which promotes rapid germination and timely seedling emergence, subsequently leading to a higher and uniform stand establishment.

Table 5. Influence of downforce on crop emergence and lint yield in singulated and hill-dropped cotton in 2017 and 2018

Seeding Configuration	Downforce (N)	Emergence (%)		Lint Yield (kg ha^{-1})	
		2017	2018	2017	2018
	0	86.7a[z]	50.4b	972a	1472a
Singulated	445	79.1bc	y	951a	y
	890	73.5c	67.8a	946a	1654a
	0	83.6ab	57.9ab	1013a	1563a
Hill-drop	445	83.6ab	y	1087a	Y
	890	82.7ab	58.0ab	1027a	1578a

[y] no data because 445 N downforce was not utilized in 2018

[z] means followed by the same letter within each column are not significantly different from each other at $p < 0.05$.

As previous research studies have concluded that obtaining an acceptable stand establishment in cotton is important for maximizing yield potential (Christiansen and Rowland, 1981), it appears that parameters such as emergence rate index or days to canopy closure could be better measures of stand establishment or yield than final emergence (or plant population) attained in the field. For future studies, measuring emergence rate or delayed emergence can also help in better evaluation of the effect of planter settings such as downforce on stand establishment in cotton.

Cultivar. The seeding configuration x cultivar interaction was not significant for crop emergence and yield in 2017 and 2018. This indicated that crop emergence and yield response to cultivar was not significantly different among the seeding configurations. During both years, a large-seeded cultivar (PHY 312) exhibited increased crop emergence than a small-seeded cultivar (DP 1555 and DP 1553 in 2017 and 2018, respectively) regardless of the seeding configuration. This trend was statistically valid for singulated cotton in 2017 and 2018, and in hill-dropped cotton in 2018. Greater seedling growth, percent emergence and survival rate for large-seeded cultivars are also reported by several researchers (Roy et al., 1996; Jerlin and Vadivelu, 2004; Ankaiah et al., 2013) in other crops as well. In cotton, seed size and density are strongly related to seedling vigor as denser and larger seed produce more vigorous seedlings than small or less dense seed (Snider et al., 2016. Virk et al., 2019). In each seeding configuration, emergence difference between cultivars was greater in strip-till conditions in 2018 (18.4% and 20.1% for singulated and hill-drop configuration, respectively) than observed in conventional tillage conditions in 2017 (5.4% and 9.4% for singulated and hill-drop configuration, respectively).

Unlike crop emergence, lint yield was not affected by cultivar in both singulated and hill-dropped cotton. Similar to the trend observed in crop emergence, yield variations among the cultivars were greater in 2018 (142 and 213 kg ha^{-1}) than yield variations in 2017 (98 and 25 kg ha^{-1}) for singulated and hill-dropped cotton, respectively. Previous research on yield comparison among seeding configurations mostly evaluated one cotton cultivar and did not investigate cultivar effects among singulated and hill-dropped cotton. A similar seeding configuration study (singulated and hill-drop; two seed hill^{-1}) conducted by Harrison et al. (2009) reported no yield differences between ST 4892BR and DP 555BG/RR cultivars when tested at two different locations in Mississippi; however, the characteristic differences (seed size, maturity, etc.) among cultivars were not reported in the study. A weak association between lint yield and seed size was also reported by Snider et al. (2013 and 2016) in a study aimed at investigating the impact of seed size and chemical composition on yield and fiber quality. In five different production environments tested in Georgia, the authors reported that cultivar selection based on larger seed size or higher seedling vigor did not influence yield. Comparable yields among cultivars in this study also implies a weak association between lint yield and seed size where large-seeded cultivar with higher seedling vigor did not produce higher yields than small-seeded or low-vigor cultivar. However, considering the higher emergence (better stand establishment) obtained with large-seeded cultivars as seen in this study, selecting large-seeded cultivars with higher seedling vigor can minimize production risks associated with poor stand establishment and influence early season management decisions.

Table 6. Cultivar effect on crop emergence and lint yield in singulated and hill-dropped cotton in 2017 and 2018

Seeding Configuration	Cultivar		Emergence (%)		Lint Yield (kg ha^{-1})	
	2017	2018	2017	2018	2017	2018
Singulated	PHY 312	PHY 312	84.5a^{z}	69.2a	1005a	1634a
	DP 1555	DP 1553	75.1b	49.1b	907a	1492a
Hill-drop	PHY 312	PHY 312	86.0a	67.2a	1055a	1677a
	DP 1555	DP 1553	80.6ab	48.8b	1030a	1464a

^{z} means followed by the same letter within each column are not significantly different from each other at $p < 0.05$.

SUMMARY AND CONCLUSIONS

Reducing seeding rates in cotton is considered a viable cost saving practice given an adequate stand establishment and higher yields can be attained at lower plant populations. Several research efforts have been made over the years to evaluate cotton yield across varying plant populations in singulated and hill-dropped cotton (Hawkins and Peacock, 1970; Kittock, 1974, Siebert, et al., 2006; Harrison et al., 2009). Recent studies reported that seeding rates can be lowered to 96,371 seed ha^{-1} in both singulated and hill-drop planted cotton without reducing yield (Harrison et al., 2009). Our results showed that cotton planted at seeding rates of 71,660 and 107,490 seed ha^{-1} showed no emergence and yield differences planted as singulated and hill-drop configuration.

The research presented here also evaluated the effect of planter downforce and cultivar on crop emergence and lint yield in singulated and hill-dropped cotton. Our results showed that a seeding configuration x downforce interaction occurred for crop emergence in 2017 and 2018. In singulated cotton, downforce effect on crop emergence varied between the years due to difference in field tillage conditions. In 2017, crop emergence was reduced at planter downforce of 445 and 890 N in conventional tillage conditions whereas the 890 N of downforce exhibited higher emergence in strip-till conditions in 2018. No emergence differences existed in hill-dropped cotton across different downforces due to presence of extra seed per hill to push through the soil crust. During both years, singulated and hill-dropped cotton had similar yields at the same planter downforce. Cultivar selection showed no emergence or yield differences among seeding configurations, although the large-seeded cultivar always exhibited significantly higher crop emergence than the small-seeded cultivar within each seeding configuration.

Grower interest in improved seed metering and precision seed placement is likely to increase with rising seed costs and technology fees motivating the trend toward lower seeding rates. Our study results indicate that cotton seeding rates can be lowered to 71,660 seed ha^{-1} in both singulated and hill-drop cotton with no adverse effects on yield, given planting and environmental conditions are optimal to achieve adequate stand establishment. This study highlighted that adjusting planter downforce for prevalent field conditions and utilizing large-seeded cultivar can help in greater stand establishment early in the season, minimizing risks associated with poor emergence especially in sub-optimal field conditions. High seed and technology fees associated with higher seeding rates in cotton production can be effectively lowered by planting reduced seeding rates without sacrificing yield, when appropriate planting equipment setup and seed technology are employed in combination with good management practices.

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