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ECONOMICS AND MARKETING

Profit-Maximizing Planting Date and Seeding Rate for Upland Cotton in the Upper Mid-South

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ABSTRACT

The objective of this research was to determine the profit-maximizing planting date and seeding rate for cotton production in the upper Mid-South. We used field trial data from Tennessee, Missouri, and Mississippi from 2016 to 2018 to estimate a cotton lint yield response function to planting date and planting population. A sensitivity analysis was conducted to compare the results for different cotton lint and seed prices. Additionally, we explored how optimal seeding rates change with late planting. We found the optimal planting date is consistent regardless of the cotton or seed price, but the optimal seeding rate depends on seed and cotton price. As seed prices increase, the optimal seeding rate decreases; and as cotton prices increase, the optimal seeding rate increases. In the case of late planting, a producer is better off using a lower seeding rate than would be optimal at an earlier planting date. These results demonstrate how prices impact planting decisions and inform producers on optimal planting dates and seeding rates to maximize profits.

Research has demonstrated that selecting the optimal planting date for row crops is a decision with little economic cost but has one of the highest economic returns (Adkins et al., 2020; Egli and Cornelius, 2009; Hu and Wiatrak, 2012). Determining the optimal planting date for cotton (*Gossypium hirsutum* L.) can be a complicated decision, requiring a producer to balance economic tradeoffs with uncertain weather. Planting too early can reduce germination, which can limit stand uniformity and cause yield loss, but waiting too late also can reduce yield potential by limiting growing periods (Anapalli et al., 2016; O'Berry et al., 2008; Pettigrew et al., 2009; Wrather et al., 2008). Studies have shown that producers have a yield-maximizing planting window in the upper Mid-South (Adkins et al., 2020; Anapalli et al., 2016; Butler et al., 2020; O'Berry et al., 2008; Pettigrew et al., 2009; Wrather et al., 2008). Unfortunately, excessive soil moisture and rainfall can delay planting during the yield-maximizing planting window. Producers often must choose to (1) plant early and accept the risk of low yields due to marginal stands, or (2) forgo early planting and accept the risk of low yields due to weather delays that force the planting date beyond the yield-maximizing window.

For example, Boquet and Clawson (2009) determined the optimal cotton planting window in Louisiana. Eight cultivars were tested at planting dates from 25 March to 5 June. They found that planting in mid-April most likely will produce greater yields than planting in mid- or early-May. However, forgoing early planting opportunities for more ideal planting dates could result in yield loss due to weather events that delay planting.

Along with yield potential, changes in planting date also could have implications for other input costs and economic returns. Seed cost, for example, is a major input cost for cotton production, and optimal seeding rates can vary by planting date (Adams et al., 2019; Butler et al., 2020; Siebert et al., 2006; Wrather et al., 2008). Wrather et al. (2008) determined the effects of plant population and planting date on cotton yields in the Mississippi Delta region from 2001 to 2005. Multiple planting dates ranging from 28 April to 2 June were tested with different plant populations. They reported a significant interaction of planting date and plant population and showed lint yield decreased as population decreased and at later dates. The highest cotton lint yields were

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found planting from late-April to early-May, and they concluded a replant might be warranted only if an early established plant population was below 17,000 seed ha^{-1}.

Furthermore, O'Berry et al. (2008) used cotton field experiments from Virginia, North Carolina, and Louisiana in 2005 and 2006 to examine how plant population and planting date impacted cotton yield, growth, and quality. They found that early planting resulted in higher yields for Louisiana, but there was no significance for yield response to planting date for Virginia and North Carolina. Louisiana recorded a greater number of heat units than Virginia and North Carolina, indicating that early planting maximized yields in areas with higher temperatures. They also found that in areas with higher temperatures such as Louisiana, a lower plant population maximized yields.

More recently Butler et al. (2020) determined the impact of plant population and planting date on cotton lint yield and fiber quality in the upper Mid-South. They found higher plant populations seeded earliest possessed the greatest yield potential but increases beyond 98,000 plants ha^{-1} failed to increase yields. Results suggested producers might be able to reduce seeding rate at later planting dates without reducing yield potential. From an economic perspective, Gwathmey et al. (2011) reported the economically optimal cotton seeding rate was between 61,000 and 150,000 seeds ha^{-1} depending on the row width and planting patterns.

These studies are important for producers to make informed decisions on maximizing yields, but little attention has been given to the economic impacts of planting date and seeding rate decisions. That is, what is the profit-maximizing seeding rate for a given planting date? This is an important question given that cotton is one of the major cash crops in the Mid-South. Recommended practices for a Tennessee cotton producer are to plant between 20 April and 10 May (Craig, 2010). The recommend plant population for optimum yield potential is between 74,000 to 148,000 plants ha^{-1} (Main, 2012). However, these recommendations are based on production data and do not consider how prices could influence these recommendations.

The objective of this study was to determine the profit-maximizing planting date and seeding rate for cotton production in the upper Mid-South. We used field trial data from Tennessee, Missouri, and Mississippi from 2016 to 2018 to estimate a cotton lint yield response function to planting date and planting population. An analysis was conducted to compare the results for different cotton lint and seed prices. Additionally, we looked at how optimal seeding rates change when planting is delayed. These results demonstrate how prices impact planting decisions and inform producers on optimal planting dates and seeding rates to maximize profits.

MATERIAL AND METHODS

Data. Data for our study were generated from field trials in five locations in Tennessee, Missouri, and Mississippi from 2016 to 2018. Field-trial planting dates, soil types, and other details on the experimental design and execution are reported in Butler et al. (2020). A 2016 pilot study evaluating plant population was conducted at Ames Plantation in Grand Junction, TN. During 2017, expanded experiments evaluating population and planting date were conducted in Grand Junction, TN; at the West Tennessee and Milan Research and Education Centers in Jackson and Milan, TN; at the Fisher Delta Research and Extension Center in Portageville, MO; and at a field site in Brooksville, MS. In 2018, experiments were repeated in Grand Junction, Jackson, and Milan, TN and Brooksville, MS. Thus, we have 10 site-years of data.

Field sites were placed throughout the upper Mid-South to capture variable environments across the locations. For the 2017 and 2018 trials, five varying seeding rates and planting dates were selected. Seeding rates included: 8,500 seeds ha^{-1}, 17,000 seeds ha^{-1}, 34,000 seeds ha^{-1}, 76,500 seeds ha^{-1}, and 119,000 seeds ha^{-1}. In 2016, the trail included only the 8,500 seeds ha^{-1}, 17,000 seeds ha^{-1}, and 119,000 seeds ha^{-1} treatments. The initial planting date at each location was targeted to fall within the range of the recommended planting window for Tennessee of 20 April to 10 May. The second and third planting dates were triggered approximately seven and 14 days, respectively, after 50% emergence of the 119,000 seeds ha^{-1} plots to normalize planting dates across the differing environments. Due to excessive rainfall, initial planting in 2017 was delayed until after 15 May in the three field sites in Tennessee.

In 2016, data were collected at one location that had four seeding rates and four replications (16 observations). In 2017, the experiment took place in all five locations and had four replications, three planting dates, and five seeding rates (300 observations). In 2018, 180 observations were made from three locations, four replications, three planting dates, and five seeding rates; but in 2018, the Brooksville site only had one planting date or 20 observations (4 replications x 5 seeding rates). This gave a total of 516 observations. Nine of these observations, or replications, were omitted due to yield not being collected, giving a total of 507 total observations.

Experiments were arranged in a randomized, complete block design with four replications and consisted 9.1-m long plots with four 96.5-cm spaced rows. All planting dates and populations were managed the same as the initial planting based upon respective state extension recommendations for cotton to standardize in-season management and simulate multiple replant dates. In each year and location, DP 1522 B2XF (DeltaPine, Bayer CropScience, Raleigh, NC), an early- to mid-maturing variety, was planted. Once plots reached relative maturity, trials were defoliated and the two center rows of each plot were harvested with a mechanical spindle picker equipped with a load-cell style weigh basket to generate seed cotton weights. For the 2017 Brooksville, MS and 2018 Milan, TN locations, turnout was assumed to be 38%. All other locations were ginned at the UT MicroGin in Jackson, TN to determine turnout. Table 1 shows the summary statistics of the cotton yields by seeding rate and Fig. 1 shows a plot of yields by planting date. More information about these data is provided in Butler et al. (2020).

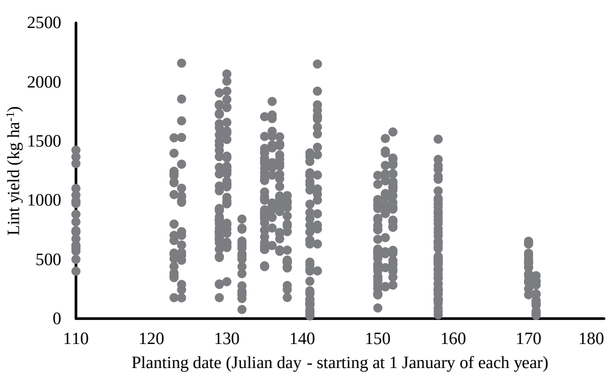

Figure 1. Lint yield of cotton by planting days from 2016-2018 in five different Upper Mid-South sites.

Prices of cotton and seed were obtained to calculate the profit-maximizing planting date and seeding rate. Cotton and seed prices were assumed in three different price scenarios in calculating the expected partial net returns. Assumed prices for cotton were \$1.1, \$1.43, and \$1.7 kg^{-1} and the assumed prices for seed were \$4, \$5, and \$6 $1{,}000^{-1}$. Prices were selected based on historic cotton prices posted reported to the U.S. Department of Agriculture Economic Research Service (2020) and seed prices from the University of Tennessee Cotton enterprise budgets (University of Tennessee Agricultural and Resource Economics Department, 2020).

Method. A quadratic response function is a common functional form used for estimating yield response to planting date (Julian day, starting at 1 January of each year) (Boyer and Smith, 2019; Boyer et al., 2015). For cotton, the similar functional form has been found to best describe cotton yield response to planting date (Adkins et al., 2020). For plant population, a quadratic is logical given yields will likely increase as seeding rates increase and at a point will begin decreasing (Main, 2012). Therefore, we estimate yield response to Julien day and plant population following this specification, expressed as:

$$y_{ti} = \beta_0 + \beta_1 D_{ti} + \beta_2 D_{ti}^2 + \beta_3 P_{ti} + \beta_4 P_{ti}^2 + \beta_5 D_{ti} \times P_{ti} + v_t + \varepsilon_{ti} \quad \text{Eq. 1.}$$

where y_{ti} is yield in site-year t and observation i; D_{ti} is Julian day when the crop was planted; P_{ti} is seeding rate ; $\beta_0,\ldots,\beta_5$ are coefficients; $v_t \sim N(0,\sigma_v^2)$ is the site-year random effect; and $\varepsilon_{ti} \sim N(0,\sigma_\varepsilon^2)$ is the random error term. The two error terms were assumed to be independent. Equation 1 is estimated with maximum likelihood using the MIXED procedure of SAS 9.4 (SAS Institute, 2013). We tested the yields for heteroscedasticity with respect to site-year and planting date using the Likelihood Ratio test (Boyer and Smith, 2019; Wooldridge, 2013). If heteroscedasticity was

Table 1. Summary statistics of lint yield (kg ha^{-1}) by seeding rate

Seeding rate in thousands	Observations	Mean	Standard deviation	Minimum	Maximum
8.5	97	470.82	279.41	23.15	1466.19
17	102	655.09	336.31	51.16	1647.53
34	104	816.34	408.84	37.11	1727.27
76.5	100	975.46	469.92	51.16	1923.53
119	104	1113.11	488.40	112.35	2159.41

present, we reported the results for the model that adjusts for the unequal variances by year (Boyer and Smith, 2019; Wooldridge, 2013). We can find the yield-maximizing planting date by solving the first-order condition of Equation 1with respect to planting day and plant population.

Economic Model. Partial budgeting was used to calculate the expected partial net returns of different planting dates and seeding populations for upland cotton. Partial budgeting means that all other costs such as fertilizer, machinery, and chemical are assumed to be consistent and the only cost that is changing is the seed price. Therefore, we can exclude all other consistent costs and only consider seed cost. Partial net returns are defined as

$$\max_{D,S} NR = py(D,S) - r \times P \qquad \text{Eq. 2.}$$

where NR is the producers expected returns (\$ ha^{-1}) for cotton; p is the price of cotton lint (\$ kg^{-1}); y is the expected lint yield (kg ha^{-1}); r is the cost of seed (\$ kg^{-1}); and P is the seed rate (1,000 ha^{-1}). The yield response function is substituted into the economic net return equation to find the net returns to various planting dates and plant population. We can find the profit-maximizing planting date by solving the first-order condition of Equation 2 with respect to planting day and seeding rate. The optimal planting date is $D^* = \frac{p(\beta_3 + \beta_5 P)}{-2p\beta_4}$ and the optimal rate is $P^* = \frac{p(\beta_1 + \beta_5 D) - r}{-2p\beta_2}$.

Economic analysis was conducted for nine scenarios of cotton and seed prices. Then, a sensitivity analysis was conducted to determine optimal seeding rates when a producer is forced to plant late. The sensitivity analysis was conducted considering the nine price scenarios.

RESULTS AND DISCUSSION

The results of the cotton lint yield response function to planting date and seeding rate are given in Table 2. All parameters were significant ($p < 0.01$). Heteroscedasticity was detected in the data across site-years and planting dates. Therefore, results are estimated using multiplicative heteroscedasticity in the variance equation, correcting for unequal variances (Wooldridge, 2013). As anticipated, yield increased with planting date until a certain date and then yields began decreasing. Similarly, lint yield increased as seeding rate increased then began decreasing as expected. These results are consistent with previous work on cotton yield response to planting date and seeding rate (Adkins et al., 2020; Butler et al., 2020).

Table 2. Cotton lint yield (kg ha^{-1}) response functions to seeding rate and planting days (Julian days) at five different sites from 2016-2018

Parameter [Z, Y]	Estimates
Intercept (β_0)	-6656.34***
Seeding rate (β_1)	21.509***
Seeding rate squared (β_2)	-0.057***
Planting days (β_3)	108.87***
Planting days squared (β_4)	-0.410***
Interaction of seeding rate and planting days (β_5)	-0.065***
-2 log-likelihood	6997
Akaike information criterion (AIC)	7033
Bayesian information criterion (BIC)	7039

[Z] Parameter estimates were corrected for heteroscedasticity using Feasible Generalized Least Squares.

[Y] Values followed by ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3 shows the economic optimal planting date and seeding rate for cotton at various cotton and seed prices. Also presented in this table is the lint yield partial net returns at the profit-maximizing planting dates and seeding rates. For all price scenarios, the model shows the optimal planting date was between 3 and 6 May. The yield-maximizing planting date was 5 May, which is similar to other findings for yield-maximizing planting dates (Adkins et al., 2020; Butler et al., 2020). Therefore, we can conclude that regardless of prices, the optimal planting date would be consistently the early part of May.

For seeding rate, however, we see two major trends. As the price of cotton increases, the economic optimal seeding rate also increases. This results in a higher optimal lint yield. Thus, despite having a higher seed price from a higher seeding rate, the producer's profits increase because higher cotton prices make the value of the additional cotton produced more valuable than the additional seed price. The second trend is that as seed price increases, the optimal seeding rate decreases. This is because the higher seed price is greater than the additional yield produced from the higher seeding rate. Two important implications for producers to consider is how seed and cotton prices can impact the economically optimal seeding rates. Higher cotton prices mean a higher seeding rate might result in increased profit, but a higher seed price means a producer would be better off planting with a lower seeding rate and having a lower yield. These results were lower than the yield-maximizing seeding rate of 118 1,000 ha^{-1}.

These results have implications for risk-management strategies for cotton producers. Without locking in harvest prices through tools like crop insurance, it is difficult for producers to know what harvest price will be at planting. However, these results show, by knowing the seed price, a producer could lower or increase seeding rates based on projected market prices. Additionally, that they should not plant yield-maximizing seed rates. For example, if the known seed price is $5 1000^{-1}, optimal seeding rates should range between 78 to 93 1000 ha^{-1}. This range can be adjusted based on futures market prices and outlook expectations.

Table 4 shows the sensitivity analysis when we assume a producer must plant late. For this example, we assumed a producer must plant on 20 May, which is past the optimal date. We chose 20 May because it is the final planting date for insured cotton and past this date, a producer would maximize profits by planting soybeans in the Mid-South (Adkins et al., 2020; Boyer and Smith, 2019). We found the optimal seeding rate at this planting date. Similar to Table 3, as seed price increases, the optimal seeding rate decreases. Likely the most important result to point out is that optimal seeding rates decreased when a producer is past the optimal planting date. This is because regardless of the prices, the yield potential decreases past the optimal planting date. This is also important for producers to consider when making a planting decision late into the planting window. The results show a profit-maximizing decision would be to reduce seed price knowing your yield potential will decrease due to late planting.

Table 3. Profit-maximizing planting date, seeding rate, lint yield, and net returns for different cotton price and seed price scenarios.

Cotton price ($ kg^{-1})	Price of Seed ($ 1,000^{-1})	Planting days	Seeding rate (1,000 ha^{-1})	Lint Yield (kg ha^{-1})	Partial Net Returns ($ ha^{-1})
1.1	4	May 4	86.56	1274	1056
1.1	5	May 5	78.00	1239	973
1.1	6	May 6	69.43	1197	900
1.43	4	May 4	94.47	1300	1481
1.43	5	May 4	87.88	1279	1390
1.43	6	May 5	81.29	1254	1305
1.7	4	May 3	98.65	1311	1834
1.7	5	May 4	93.11	1296	1738
1.7	6	May 4	87.57	1278	1647

Table 4. Profit-maximizing seeding rate, lint yield, and net returns for different cotton price and seed price scenarios when planted late (20 May)

Cotton price ($ kg^{-1})	Price of Seed ($ 1,000^{-1})	Seeding rate (1,000 ha^{-1})	Lint Yield (kg ha^{-1})	Partial Net Returns ($ ha^{-1})
1.1	4	77.56	1150.19	954.96
1.1	5	69.40	1116.79	881.48
1.1	6	61.24	1075.98	816.16
1.43	4	85.10	1174.43	1339.04
1.43	5	78.82	1154.67	1257.09
1.43	6	72.54	1130.52	1181.41
1.7	4	89.09	1184.70	1657.65
1.7	5	83.80	1170.72	1571.20
1.7	6	78.52	1153.63	1490.04

CONCLUSION

There has been little attention given to the economic impacts of planting date and seeding rate decisions on cotton lint production. Therefore, the goal of this study was to determine the profit-maximizing planting date and seeding rate for cotton production in the upper Mid-South. We use field trial data from Tennessee, Missouri, and Mississippi from 2016 to 2018 to estimate a cotton lint yield response function to planting date and planting population. A sensitivity analysis was conducted to compare the results for different cotton lint and seed prices.

We found the optimal planting date was between 3 and 6 May regardless of the cotton or seed price. Optimal seeding rate does depend on cost of seed and the price of cotton. As seed prices increase, the optimal seeding rate decreases. On the other hand, as cotton prices increase, the optimal seeding rate increases. Additionally, if a producer is forced to plant late, the optimal seeding rate decreases. These results demonstrate how prices impact planting decisions and inform producers on optimal planting dates and seeding rates to maximize profits.

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