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AGRONOMY & SOILS

Effects of Different Cover Crops and Cotton Planting Rates on Cotton Production in a No-Till System

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ABSTRACT

Single species cover crops and cover crop mixtures, especially legumes, can protect the soil surface and increase soil organic matter in a no-till system. Cotton producers who focus on soil health are interested in maximizing their economic return by minimizing production cost while maintaining yield. Producers can accomplish this by manipulating cotton seeding rates. From 2017 to 2020 field experiments were run in central Alabama to evaluate the effects of cover crop species (cereal rye [*Secale cereale* L.], crimson clover [*Trifolium incarnatum* L.], and cereal rye + crimson clover) and cotton seeding rates (54,116, 108,232, and 180,387 seeds ha^{-1}) on no-till cotton production. During the experiments, biomass for cereal rye and crimson clover was similar (5,540 kg ha^{-1}) but was lower compared to their mixture (6,469 kg ha^{-1}). Seed cotton yield in 2018 and 2020 was similar, averaging 4,597 kg ha^{-1}. In 2019 the yield was substantially reduced to 2,068 kg ha^{-1} due to severe drought. Profit in 2019 was $1,484 ha^{-1} compared to higher average profit of $6,209 ha^{-1} in 2018 and 2020. Yield and profitability were greater using the medium or high seeding rate during the 2018 and 2019 seasons. However, under severe drought conditions (2019 season) the low cotton seeding rate was similar in yield and profitability as the medium and high seeding rates. Overall, yield and profits were influenced by cotton seeding rate and weather and not by cover crop type.

In the past two decades, the use of cover crops in no-till cotton production systems has been steadily increasing as more producers realize soil health benefits while maintaining cotton yield (Dang et al., 2020; Wallander et al., 2021). The primary benefits of cover crops include reducing soil erosion and runoff, weed suppression, increasing soil organic matter, and improving soil water conservation and infiltration (Balkcom et al., 2007; Clark, 2019; Reeves, 1994; Seepaul et al., 2023).

Cereal rye (*Secale cereale* L.) is a cover crop widely adopted in the southern U.S., including Alabama, because of its high biomass production potential of up to 7,840 kg ha^{-1} (Smith and Gamble, 2020a). Cereal rye can be used to suppress weeds by mulch effect and allelopathy. Allelopathy is the leaching of chemicals (phenolics, flavonoids, or terpenoids) during the decomposition of cover crop residue (Macías et al., 2007). These allelochemicals act as a natural pre-emergence herbicide for weed suppression (Masiunas et al., 1995). Also, in no-till systems, cereal rye sequesters carbon (C) but does not typically release nitrogen (N) to the main crop due to the associated high C:N ratio (Lowry and Brainard, 2016).

Crimson clover (*Trifolium incarnatum* L.) can fix N in addition to generating substantial amounts of residue. In the southern U.S., crimson clover can produce up to 6,150 kg ha^{-1} of dry biomass and release approximately 170 kg N ha^{-1} (Smith and Gamble, 2020b) making it attractive as a stand-alone cover crop or as part of a cover crop blend, such as with cereal rye. This mixture has value for conventional and organic producers, both for effective weed control and for meeting nitrogen demands of the following crop (Reberg-Horton et al., 2012; Vann et al., 2017).

Proper cover crop management is crucial for successful planting of cash crops directly into previously flattened and desiccated residue cover. Flattening of cover crops can be accomplished by rolling/crimping against a firm soil surface (Ashford and Reeves, 2003; Kornecki, 2018; Kornecki et al., 2006). To accelerate the termination rate of cover crops, producers apply herbicides to ensure cover crop residue is desiccated before planting, especially in early spring when weather is often unpredictable. Also, waiting for the suggested growth stage of different cover crop species to generate optimum biomass might interfere with recommended main crop planting dates. Results from a field study by Kornecki et al. (2009a) showed

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that applying glyphosate in addition to rolling provided termination rates ranging from 96 to 98% for cereal rye seven days after rolling. Lower emergence was also shown in Denton et al. (2023) relying on mechanical termination alone compared to either chemical or chemical plus mechanical termination.

Cotton plant population density also plays a substantial role in overall cotton productivity and profitability. According to Smith et al. (2022), costs associated with cottonseed were 15 to 20% of the total production cost for cotton. In another field study conducted by Gwathmey et al. (2010), cotton lint yield was maintained at plant populations between 74,000 and 111,000 plants ha^{-1}. Boyer et al. (2020) examined different seeding rates of conventional cotton production across the upper Southeast at 8,500, 17,000, 34,000, 76,500, and 119,000 seeds ha^{-1}. They concluded that with increased seed prices, producers tended to reduce seeding rates to maximize profitability. Also, if cotton lint price was higher, then cotton planting rate tended to be higher. Above referenced studies showed results of different planting rates and benefits for cotton only under conventional tillage practices. Such benefits include mechanical weed control and improved aeration, nutrient management, and crop seeding (USDA-ERS, 2020). A gap in research exists evaluating the yield and profitability of various cotton seeding rates planted into multiple cover cropping systems. Therefore, the objective of this study was to determine the effects of three different cotton seeding rates planted into two different cover crops (cereal rye and crimson clover) as well as their mixture on cotton emergence, cotton population, seed cotton yield, and economic returns in a conservation tillage system.

MATERIALS AND METHODS

A field experiment was initiated in 2017 in central Alabama at the Auburn University E.V. Smith Research and Extension Center in Shorter, AL (32.39° N, -85.92° W). The soil type was a Compass loamy sand (Coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults). Cover crops included cereal rye (var. Wrens Abruzzi), crimson clover (var. Dixie), and a blend of the two were planted in November 2017, 2018, and 2019. The planting rate for cereal rye was 100 kg ha^{-1} and crimson clover was planted at a rate of 28 kg ha^{-1} as recommended by USDA-ARS (2016a, b), respectively. Planting rate for the blend was 50 and 14 kg ha^{-1}, for cereal rye and crimson clover, respectively. Cereal rye plots received 13.6 kg N ha^{-1}; plots with crimson clover and crimson clover plus cereal rye were not fertilized.

Field activities for each of the three growing seasons are provided in Table 1. The experiment was a split-plot design with four replications. The main plots were cover crop types (1. cereal rye, 2. crimson clover, 3. mixture) randomly assigned to the entire experimental area with four replications (12 main plots). The randomization process was performed according to the procedure described by Gomez and Gomez (1984). The experimental layout is shown in Fig. 1 with each plot measuring 9.1m in length by 3.7 m wide.

Data collection for cover crop biomass was performed by randomly tossing a 0.5 m^2 wire frame in each plot. Biomass was cut at ground level and placed in paper sacks and oven dried (Grieve Corporation, Round Lake, IL) for 72 h at 55 °C. Samples were weighed and results were expressed in kg ha^{-1} of dry biomass. Plant heights were collected by placing a

Table 1. Field activities during the 2018, 2019, and 2020 growing seasons at the E.V Smith Research Center in central Alabama

Field Activity	Growing Season		
	2018	2019	2020
Planted cover crops	15 Nov 2017	15 Nov 2018	06 Nov 2019
Biomass and plant heights collected	13 Apr 2018	17 Apr 2019	15 Apr 2020
Rolled/crimped cover crops	19 Apr 2018	23 Apr 2019	22 Apr 2020
Cover crop burndown	20 Apr 2018	23 Apr 2019	22 Apr 2020
Planted cotton	11 May 2018	22 May 2019	14 May 2020
Cotton emergence collection started	21 May 2018	28 May 2019	26 May 2020
Cotton emergence collection completed	06 June 2018	13 June 2019	08 June 2020
Applied nitrogen to cotton	28 June 2018	03 July 2019	01 July 2020
Counted final cotton population	03 Aug 2018	25 July 2019	20 July 2020
Cotton harvested	06 Oct 2018	07 Oct 2019	22 Oct 2020

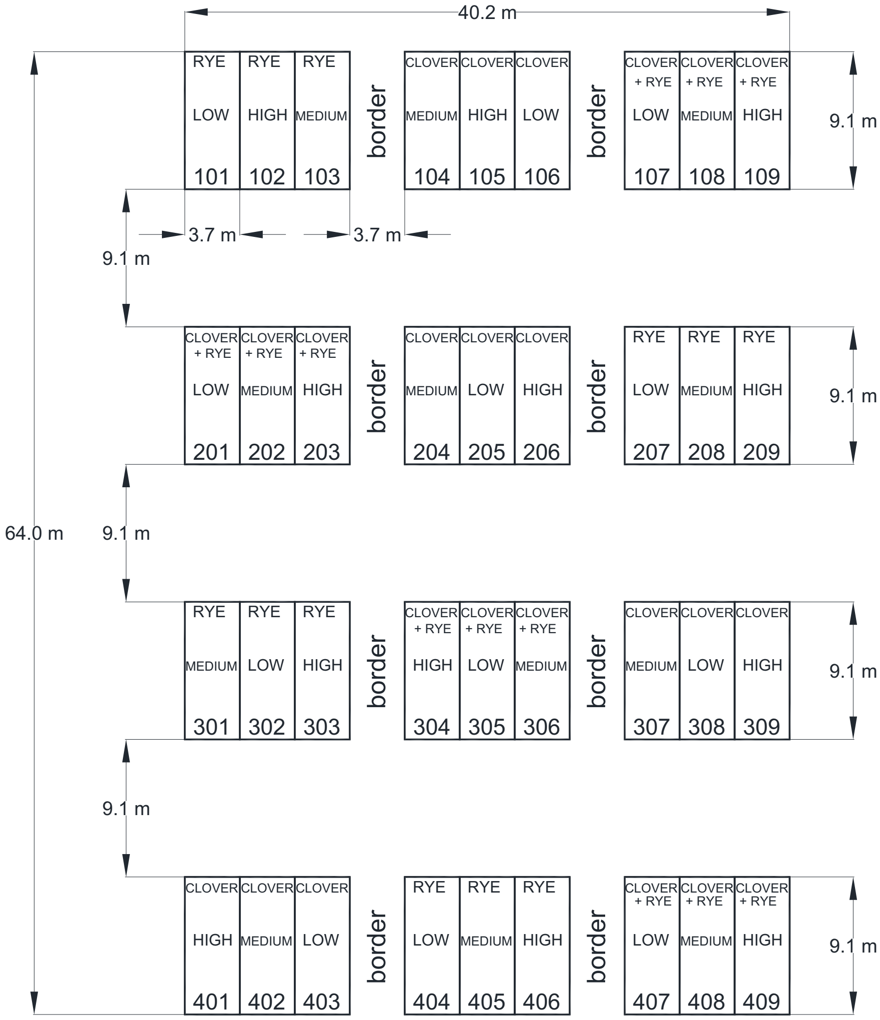

Figure 1. Experimental layout: Split plot design with 4 replications. Main plots are three different cover crops: cereal rye, crimson clover and the mixture between cereal rye and crimson clover. The submain plots within each main plot are randomly assigned cotton planting rates: low (54,116 plants ha^{-1}), medium (108,232 plants ha^{-1}), and high (180,387 plants ha^{-1}). Three-digit numbers from 101 to 409 (numbers on the bottom of rectangular plot) represent experimental unit number, e.g., for 409 experimental unit, the first digit is the replication number (4), second and third digits are plot number (09).

wooden ruler at ground level and taking the height measurement to the top of the seed head. Heights for both rye and clover were collected six times each per plot for both the single and mixture plots.

During the 2018 to 2020 growing seasons, rolling/crimping was performed when cereal rye was at the milk growth stage (Zadoks #77) (Zadoks et al., 1974) and crimson clover was in flowering stage. An experimental 3.7-m wide straight bar roller, developed at the USDA-ARS National Soil Dynamics Laboratory in Auburn, AL, was mounted on the three-point hitch of a John Deere 7730 tractor. After rolling/crimping, glyphosate herbicide (Roundup^{TM} Weather Max, Bayer CropScience, St. Louis, MO) was applied at 1.06 kg a.e. ha^{-1} separately using a John Deere 6700 self-propelled sprayer.

Cotton (Phytogen 330 W3FE; Corteva Agrisciences, Indianapolis, IN) was planted using a John Deere XP 1700 MaxEmerge planter (0.91-m in-row spacing) with Dawn^{TM} model 1572 row cleaners (Dawn Equipment Company, Sycamore, IL). The planter was outfitted with Precision Planting (Precision Planting, Tremont, IL) vSet meters and Delta-Force automated downforce control. The cotton planting rates (sub plots) were randomly assigned to each of the main plots (total of 36 subplots). The three cotton seeding rates were 54,116 (low), 108,232 (medium), and 180,387 (high) seeds ha^{-1}. Seeding rates selected in this experiment approximated the range of 54,900 to 180,830 seeds ha^{-1} used by Kimura and Ramirez (2018). Cotton was fertilized prior to flowering with 27.2 kg N ha^{-1} liquid urea ammonium nitrate for all plots.

Cotton emergence assessment began at the first visible seedling. Plants were then counted at two random locations per row along a 1.5-m long measuring pole on the middle two rows of each four-row plot (four measurements per plot). Stand counts were collected twice per week until no new plant emergence was observed, approximately 3 weeks after the first collection date. To compare cotton plant emergence rates across seeding cotton rates and different cover crops, emergence rate index (ERI) in percent per day was used. Higher ERI values indicated cotton plants having faster emergence. ERI was calculated using the procedure described by Erbach (1982) and Aikins et al. (2019):

$$ERI = \sum_{n=first}^{last} \frac{[\%n - \%(n-1)]}{n}$$

where: %n = percent plants emerged on day n, %(n-1) = percent plants emerged on day n-1, n = number of days after planting, first = number of days after planting that the first plant emerged (first counting day), and last = number of days after planting when emergence was considered complete (last counting day).

Final cotton populations were collected mid-growing season by using the average of four 1.5-m random lengths among the middle two rows of each plot, expressed in number of plants per hectare. In each year, cotton was harvested during the third week of October, with a Case IH 2555 4-row cotton picker (Case IH, Racine, WI) with weighing basket system.

The rates of monetary returns for each cover crop and cotton seeding rates were established by using cost for a particular operation and the farm prices of seed cotton. The machinery costs were based on data from the Department of Agricultural Economics Budget Report (Mississippi State University, 2022), and other necessary input costs such as cotton seed were obtained from local sources. To reflect current market price levels, all revenue calculations were based on 2023 prices. The cost of drilling the cover crop varied by treatment as different equipment and fertilization strategies were used. It cost \$320.46 ha^{-1} to drill cereal rye (Wrens Abruzzi var.), which included drilling, fertilization, chemical termination/rolling, machinery, fuel, and labor. An additional cost of \$23.72 ha^{-1} was associated with cereal rye for N fertilization (30-0-0). It cost \$252.76 ha^{-1} to seed crimson clover (Dixie var.). The total cost for a mixture of cereal rye and crimson clover was \$266.97 ha^{-1}. All costs for crimson clover and the mixture included the same operations as for cereal rye but excluded nitrogen fertilization. Cost of cotton seed as determined from local Alabama sources were \$226.44, \$418.27, and \$674.04 ha^{-1} for low, medium, and high seeding rate, respectively. Budgets were generated for each cover crop and cotton seeding rate to establish the cost for a specific farming operation. Total cotton production costs were based on the Alabama Cooperative Extension Service: Reduced Tillage Cotton Planning Budget (ACES, 2023). Based on total production costs from all farming operations and seed cotton yield revenue, net profits were calculated yearly for each cover crop and seeding rate.

Cover crops, cotton planting rates, and years were considered fixed effects, however replications and interactions of replications with covers were random effects (Gomez and Gomez, 1984). Where differences in each year for dependent variables were significant, and when interactions between cover crops, cotton seeding rates, and years occurred, data were analyzed separately. Data were subjected to analysis of variance using the GLIMMIX procedure in SAS software v 9.4 (SAS, 2023), and for different cover crops/cotton seeding rates (COVER*RATE) t-test grouping for the Least Squares Means was performed at alpha (α) = 0.1.

RESULTS AND DISCUSSION

In 2019, severe drought and excessive high temperatures affected cotton growth and substantially reduced both seed cotton yield and profit, but did not impact cover crop production, cotton emergence rate, and cotton population. This negative impact on cotton yield was associated with inclement weather conditions that occurred after final cotton plant establishment. Precipitation and temperature data from three growing seasons are presented in Table 2. Significant differences were reported in biomass production (height and dry biomass weight) of crimson clover, cereal rye, and the mixture (crimson clover and cereal rye) among these cover crops (COVER) and among three years of evaluation (YEAR), with significant interactions between COVER*YEAR (Table 3). Because of these differences, cover crop height and dry biomass were analyzed again separately by year and cover. Significant differences in the emergence rate index (ERI), cotton population, and seed cotton yield were reported for variable YEAR, with *p*-values of < 0.0001, < 0.0001, and < 0.0001, for 2018, 2019, and 2020, respectively.

Table 2. Weather information during 2018-2020 growing seasons (AWIS, 2020)

Activities	Growing Season								
	2018			2019			2020		
Weather data for specific periods with respect to cover crops	Planted 15 Nov 2017 Terminated 19 Apr 2018 Number of days: 156			Planted 15 Nov 2018 Terminated 23 Apr 2019 Number of days: 158			Planted 06 Nov 2019 Terminated 22 Apr 2020 Number of days: 168		
	Rainfall (mm)	Temp °C Max	Temp °C Min	Rainfall (mm)	Temp °C Max	Temp °C Min	Rainfall (mm)	Temp °C Max	Temp °C Min
From planting to termination	424	17.9	5.0	661	18.7	6.4	918	19.6	6.9
Weather data for specific periods with respect to cotton	Planted 11 May 2018 Harvested 06 Oct 2018 Number of days: 148			Planted 22 May 2019 Harvested 07 Oct 2019 Number of days: 137			Planted 14 May 2020 Harvested 22 Oct 2020 Number of days: 162		
	Rainfall (mm)	Temp °C Max	Temp °C Min	Rainfall (mm)	Temp °C Max	Temp °C Min	Rainfall (mm)	Temp °C Max	Temp °C Min
From planting to harvest	477	31.9	21.4	204	33.8	20.8	628	30.4	19.9

Table 3. F-values and corresponding probabilities for cover crop height and biomass

Source	DF[z]	Height F-Value	Height *p*-value	DF	Biomass F-Value	Biomass *p*-value
Year	2	48.18	<0.0001	2	4.53	0.0132
Cover	3	3128.74	<0.0001	2	9.50	0.0002
Cover*year	6	5.98	<0.0001	4	2.74	0.0328

[z]DF = degrees of freedom

F-values and probabilities for ERI, cotton population, and seed cotton yield are shown in Table 4. Because of significant differences among the years, ERI, cotton population, and seed cotton yield data were reanalyzed separately by year.

Cover Crop Production. For the three experimental years (Table 5), the mixture (rye + clover) produced biomass of 6,469 kg ha^{-1} compared to lower biomass for clover (5633 kg ha^{-1}) and rye (5446 kg ha^{-1}). Plant height for the single cereal rye species was greater in 2019 than in 2018 and 2020. Also, there was no difference in plant height between rye in mixture for all growing seasons. Crimson clover plant heights for single species and in the mixture were no different in 2018 and 2019 but were greater in mixture compared to single species in 2020. Cover crop biomass production for the mixture was similar to cereal rye in 2018 but significantly greatest out of all cover crops in 2019. Rye was also similar to crimson clover alone in 2018 and 2019 alone. No differences in biomass production

Table 4. F-values and corresponding probabilities for emergence rate index (ERI), cotton population, seed cotton yield, and profit

Effect	DF[z]	ERI F-Value	ERI *p*-value	Cotton Population F-Value	Cotton Population *p*-value	Seed Cotton Yield F-Value	Seed Cotton Yield *p*-value	Profit F-Value	Profit *p*-value
YEAR	2	92.61	<0.0001	18.02	<0.0001	524.73	<0.0001	524.73	<0.0001
RATE	2	3.72	0.0383	588.03	<0.0001	16.31	<0.0001	5.60	0.0055
COVER	2	1.71	0.2582	4.46	0.0651	0.25	0.7886	0.15	0.8622
RATE*COVER	4	0.35	0.8461	1.73	0.3556	0.60	0.6654	0.60	0.6654
YEAR*RATE	4	1.41	0.2387	1.14	0.3467	5.52	0.0006	5.52	0.0006
YEAR*COVER	4	2.35	0.0626	0.31	0.8671	1.61	0.1812	1.61	0.1812

[z]DF = Degrees of freedom

Table 5. Cover crop production data (height and biomass) for cereal rye, crimson clover, and mixture (cereal rye + crimson clover) for 2018-2020 growing seasons

Cover Crop Production		Year 2018	2019	2020	3-Year Average
Crimson Clover	Height (cm)	66.8 b[z]	69.7 b	49.4 c	62.0 c
Cereal Rye		161.3 a	169.6 a	159.6 a	163.5 a
Rye + Clover	Clover Height (cm)	70.0 b	68.7 b	57.8 b	65.5 b
	Rye Height (cm)	160.7 a	166.6 a	159.4 a	162.3 a
Crimson Clover	Biomass (kg ha^{-1})	5,063 B	5,918 B	5,619 A	5,633 B
Cereal Rye		5,547 AB	5,410 B	5,381 A	5,446 B
Rye + Clover		6,218 A	7,475 A	5,715 A	6,469 A

[z]Comparisons between Least Squares Means (LS-Means) are valid only within each column for each year. LS-Means are compared for each cover crop within each year using Tukey-Kramer grouping procedure at alpha = 0.1. LS-Means followed by the same lower-case letter (for the plant height) are not statistically different. LS-Means followed by the same upper-case letter (for the plant biomass) are not statistically different.

were observed across cover crops in 2020. The cereal rye cover crop biomass production in this study during three growing seasons followed the average biomass production of 5570 kg ha^{-1} in Alabama for cereal rye (USDA-ARS, 2016a). The mixture of crimson clover and cereal rye production agreed with Vann et al. (2017), who reported biomass mixture between 3,820 to 6,610 kg ha^{-1}. Average crimson clover biomass production was similar to results by Kornecki et al. (2015) reporting 6,013 kg ha^{-1}.

Cotton Emergence Rate Index (ERI). Significant differences in ERI (Table 4) were reported among the years (p-value < 0.0001), cotton seeding rate (p-value = 0.0383), and interactions between cover crop and year (p-value = 0.0626). Therefore, ERI data were analyzed by YEAR separately (Table 6). In each growing season, there were no significant differences in ERI between cover crop types and three cotton planting rates associated with each cover. Comparing 3 years, in 2018 the average ERI was lower than in 2019 and 2020, but the highest ERI was reported in 2019. These lower ERI values (7.9%) in 2018 might be related to wet field conditions that inhibited cotton emergence and possibly from leaching of allelopathic chemicals that act like preemergence herbicides from desiccated cereal rye residue (Chou and Patrick, 1976; Masiunas et al., 1995; Shekoofa et al., 2020). Leaching of these chemicals can suppress cotton germination as water flows through the cover crop residue during its decay, dissolving allelopathic compounds in rainwater (Kornecki, 2020; Nakano et al., 2003). In 2018 during the first 10 days of cotton emergence, there were 9 days of rainfall totaling 118 mm, which caused wet field conditions, compared to only 2 days in 2019 and 2020 with respective rainfalls of 19 mm and 45 mm (AWIS, 2020). In contrast, in 2019 higher ERI values (11.4%) indicated faster cotton emergence than in 2018 and 2020. These results agreed with a previous field experiment with a cereal rye cover crop by Kornecki (2020), who reported ERI values between 10.1 and 11.0, which indicated no restriction in cotton emergence from the rolled and crimped rye residue in cotton planting. ERI averaged over cover crops and all seasons was significantly lower (9.2) for high seeding rate compared to higher ERI for medium (9.7) and low seeding rate (9.8). Across cover crops and seeding rates, the lowest cotton emergence rate index of 7.9 was measured in 2018, followed by a higher ERI of 9.2 in 2020, and the highest ERI of 11.3 in 2019.

Cotton Population. Significant differences in cotton population (Table 4) were observed among years (p-value < 0.0001) and cotton seeding rates (p-value < 0.0001). Cotton population of 35,000 plants ha^{-1} was identified by Adams et al. (2019), as a threshold below which cotton yield can decline quickly, creating substantial economic risk to producers. Results from this experiment (Table 7) indicated that plant population across 3 years with respect to cover crop and planting rate treatments were above this threshold. Comparing all years, final cotton population was proportional to cotton planting rates (Table 7) with low, medium, and high at 40,663, 71,857, and 114,215 plants ha^{-1}, respectively. Percentages of population target were 75, 66, and 63 at low, medium, and high, respectively. These population percentages agree with the trend noticed in Hall et al. (2024) with emergence percentages of 92.5, 86, and 80 associated with the cotton planting densities of 49,400, 98,800, and 148,200 seed ha^{-1}, respectively.

Table 6. Emergence rate index (ERI) in % per day for cover crops and cotton planting rates during 2018-2020 growing seasons

Cover Crop	Cotton Seeding Rate	Growing Season			3-Year Average
		2018	2019	2020	
Crimson Clover	Low	6.9 a[z]	11.6 a	10.2 a	9.6 a
	Medium	8.0 a	10.9 a	9.6 a	9.5 a
	High	6.5 a	10.6 a	9.1 a	8.7 a
Rye + Clover	Low	8.0 a	11.6 a	9.3 a	9.6 a
	Medium	8.7 a	11.8 a	9.0 a	9.8 a
	High	7.9 a	11.0 a	8.4 a	9.1 a
Cereal Rye	Low	8.2 a	11.9 a	10.3 a	10.1 a
	Medium	8.6 a	11.7 a	9.0 a	9.8 a
	High	8.2a	11.5 a	9.2 a	9.6 a
p-value		N/S	N/S	N/S	N/S
Cotton Seeding Rate					
Low		7.7 a[y]	11.7 a	9.9 a	9.8 a
Medium		8.4 a	11.4 a	9.2 ab	9.7 a
High		7.5 a	11.0 a	8.9 b	9.2 b
p-value		0.2066	0.1562	0.0469	0.0383
Yearly ERI across cover crops and rates		7.9 C[x]	11.4 A	9.4 B	*p*-value <0.0001

[z]Comparisons between Least Squares Means (LS-Means) are valid only within each column for each year (cover crops and cotton seeding rates).

[y]Comparisons between LS-Means are valid only within each column for each year (cotton seeding rates). LS-Means are compared for each cover crop within each year using Tukey-Kramer grouping procedure at alpha = 0.1. LS-Means followed by the same lower-case letter are not statistically different.

[x]Different upper-case letters in the last row indicate significant differences in cotton emergence rate index (ERI) among years (growing seasons).

Table 7. Cotton population (plants ha^{-1}) for cover crops and cotton planting rates during 2018-2020 growing seasons

Cover Crop	Cotton Seeding Rate	Growing Season			3-Year Average
		2018	2019	2020	
Crimson Clover	Low	35,879 c[z]	40,812 c	47,540 c	41,410 c
	Medium	60,994 b	66,376 b	71,758 b	66,376 b
	High	92,388 a	110,776 a	120,643 a	107,936 a
Rye + Clover	Low	36,776 c	37,673 c	42,606 c	39,018 c
	Medium	72,206 b	71,758 b	81,625 b	75,196 b
	High	110,776 a	117,055 a	121,989 a	116,607 a
Cereal Rye	Low	34,982 c	40,364 c	49,334 c	41,560 c
	Medium	66,376 b	76,691 b	78,934 b	74,000 b
	High	108,534 a	125,576 a	120,195 a	118,102 a
Yearly cotton population across cover crops and rates		68,768 C[y]	76,343 B	81,625 A	*p*-value < 0.0001

[z]Comparisons between Least Squares Means (LS-Means) are valid only within each column for each year. LS-Means are compared for each cover crop within each year using Tukey-Kramer grouping procedure at alpha = 0.1 in SAS. LS-Means followed by the same letter are not statistically different.

[y]Different upper-case letters in the last row indicate significant differences in cotton plant population among years (growing seasons).

Typically, increasing seeding rate by approximately 20% has been recommended to account for lost seedling emergence. For example, according to Collins and Edmisten (2015), to reach a population of 74,130 plants ha^{-1}, the recommended planting rate is 86,960 seed ha^{-1}. In this experiment, final plant population was 25 to 37% less that seed cotton planting, exceeding the 20% recommended higher seed planting rate. In general, cotton population was not influenced by the different cover crop species within a given season and was not negatively impacted by high residue cover crop conditions. However, planting at higher populations resulted in lower percentage of plants with respect to target population indicating a source of wasted seed.

Seed Cotton Yield. Cotton yield was significantly different among years and cotton seed planting rates (Table 4) with *p*-value < 0.0001, and there were significant interactions between seeding rate and years (RATE*YEAR) with *p*-value = 0.0006. In contrast, across the three growing seasons, yield was not affected by cover crop treatment (*p*-value = 0.7886). Seed cotton yield for each growing season for cover crop and cotton planting rate treatments are shown in Table 8. In 2019 the yield was substantially reduced and was only 45% of yield generated in 2018 and 2020, due to prolonged drought and unusually high temperatures above 33 °C (Table 2). Specifically, during the cotton growing period from planting to harvesting in 2018 and 2020, total respective rainfall amounts were 477 mm and 628 mm. In contrast, for 2019 during the same period, rainfall was 204 mm, 273 mm less than 2018 and 424 mm less than 2020 (Table 2). To reflect more typical season conditions, yield was reanalyzed using the 2018 and 2020 seasons combined, excluding the 2019 season. Overall, no significant differences were realized across seasons (data not shown; *p*-value = 0.4972) averaging 4597 kg ha^{-1}. Likewise, yield was not influenced by cover type (*p*-value = 0.5832), but cotton planting rate had impact on yield (*p*-value < 0.0001). Also, there was a significant interaction between Cover*Year with *p*-value = 0.0503. Yield was proportional to cotton seeding rate with significant differences between each rate with values of 4,953 kg ha^{-1}, 4,666 kg ha^{-1}, and 4,172 kg ha^{-1} for high, medium, and low, respectively. Similar results were reported by Hall et al. (2024) with lint yield of 976 kg lint ha^{-1} for a 148,200 seed ha^{-1} planting rate compared to 922 kg lint ha^{-1} for the 98,800 seed ha^{-1} planting rate. In the same study, a 9% lint increase also was reported when the planting rate increased from 49,400 seeds ha^{-1} (839 kg lint ha^{-1}) to 98,800 seeds ha^{-1}.

Because of a significant interaction for Year*Cover variables, yield data were analyzed for 2018 and 2020 to determine if cover type and planting rate had an impact on cotton yield. In 2018, both cotton seeding rates and cover crop treatments had an impact on yield with respective *p*-values of < 0.0001 and 0.0731 (Table 8). Yield for the cover crop mixture was higher than

Table 8. Seed cotton yield (kg ha^{-1}) for cover crops and cotton planting rates during 2018-2020 growing seasons

Growing Season	2018	2019	2020	3-Year Average
Cover Crop Type (Cover)				
Crimson Clover	4,408 b[z]	2,082 a	4,639 a	3,709 a
Rye + Clover	4,738 a	2,012 a	4,582 a	3,777 a
Cereal Rye	4,728 ab	2,109 a	4,487 a	3,775 a
p-value at α = 0.1	0.0731	0.8054	0.6779	0.7886
Cotton Seeding Rate (Rate)				
Low	4,133 b	2,052 ab	4,211 b	3,466 b
Medium	4,779 a	2,172 a	4,553 b	3,835 a
High	4,962 a	1,978 b	4,944 a	3,961 a
p-value at α = 0.1	<0.0001	0.0246	0.0015	<0.0001
Interaction				
Cover x Rate	0.6945	0.2089	0.4170	Year x Rate: *p*-value = 0.0006
Yield averaged over treatments	4,625 A[y]	2,068 B	4,569 A	Year: *p*-value <0.0001

[z]Comparisons between Least Squares Means (LS-Means) are valid only within each column for each year. LS-Means are compared for each cover crop and seeding rates within each year using Tukey-Kramer grouping procedure at alpha = 0.1. LS-Means followed by the same letter are not statistically different.

[y]Different upper-case letters in the last row indicate significant differences in seed cotton yield among growing seasons.

for single crimson clover. Although yield for rye was no different than for mixture and clover. For cotton planting rate treatments, higher yield was obtained for high and medium cotton planting rates compared with lower yield at low planting rate (Table 8). Similar yield between high and medium planting rates can be explained with the medium planting rate having increased plant spacing causing more branching and cotton bolls (Jost and Steward, 2005; Kornecki et al., 2009b). For example, in 2018, the cotton population of 66,526 plants ha^{-1} (medium seeding rate treatment) reduced seed use by 36% and had similar yield compared to cotton population of 103,900 plants ha^{-1} (high seeding rate treatment). Results are consistent with a 2-year study conducted in Texas that evaluated four cotton seeding rates (54,900, 109,790, 142,080, and 180,830 seeds ha^{-1}) without cover crops to determine the optimal seeding rate for cotton yield (Kimura and Ramirez, 2018). They found that under optimal weather conditions, the lower seeding rate of 54,900 seeds ha^{-1} produced the same yield and generated higher net income compared to the higher seeding rates.

In 2020, yield was no different among cover crop treatments (p-value = 0.6779) but was significantly different for cotton seeding rate treatments (p-value = 0.0015). Higher cotton yield was reported for high planting rate compared to lower yield for medium and low planting rates without yield difference between these rates (Table 8).

Economic Aspects. Profits from seed cotton yield (Table 4) were significantly different across growing seasons (p-value < 0.0001) and cotton seeding rates (p-value = 0.0055). In addition, there was a significant interaction between cotton planting rate and year (p-value = 0.0006).

Higher profits were obtained in 2018 and 2020 ($6,261 and $6,157 ha^{-1}, respectively) compared to 2019 profits ($1,484 ha^{-1}) (Table 9). Decreased profits in 2019 can be attributed to substantial reduction in cotton seed yield caused by prolonged severe drought and

Table 9. Economic analysis for cover crops and cotton planting rates for 2018 - 2020 growing seasons with profit ($ ha^{-1}).

Cover Crop	Cotton Seeding Rate	2018	2019	2020	3-Year Average
	Seeds ha^{-1}	Profit[z] ($ ha^{-1})			
Crimson Clover[w]	Low[y]	5,437 d[x]	1,890 a	5,615 a	4,314 a
	Medium[v]	6,106 abcd	1,725 a	6,601 a	4,811 a
	High[u]	6,105 abcd	1,000 a	6,725 a	4,610 a
Rye + Clover[t]	Low	5,580 cd	1,648 a	6,170 a	4,466 a
	Medium	6,849 ab	1,533 a	5,726 a	4,702 a
	High	7,032 a	997 a	6,686 a	4,905 a
Cereal Rye[s]	Low	5,652 bcd	1,469 a	5,319 a	4,146 a
	Medium	6,756 abc	1,847 a	6,115 a	4,906 a
	High	6,834 abc	1,250 a	6,455 a	4,846 a
Yearly average across all treatments		6,261 A**	1,484 B	6,157 A	4,634

[z]The farm price for seed cotton in 2022 was $1.8678 per kg (latest price available). Revenue = Farm Price Seed cotton ($/kg) x Seed Cotton Yield (kg/ha^{-1}); Profit = Revenue - Cotton Production Cost - Cover Treatment Cost - Cotton Seeding Cost; Cotton production cost (per hectare) was $1,657.57 (ACES 2023) Cotton Production Budget.

[y]Cotton (Phytogen 400 W3FE var.) planted at 54,115 seeds per ha^{-1} has a seeding cost of $226.44 per ha^{-1}.

[x]Comparisons between Least Squares Means (LS-Means) are valid only within each column for each year. LS-Means are compared for each cover crop and seeding rates within each year using Tukey-Kramer grouping procedure at alpha = 0.1. LS-Means followed by the same letter are not statistically different. **Different upper-case letters in the last row indicate significant differences in profits among growing seasons.

[w]Crimson Clover (Dixie var.) drilled at 28 kg/ha^{-1} has a management cost of $252.76 per ha^{-1}.

[v]Cotton (Phytogen 400 W3FE var.) planted at 108,230 seeds per ha^{-1} has a seeding cost of $418.27 per ha^{-1}.

[u]Cotton (Phytogen 400 W3FE var.) planted at 180,383 seeds per ha^{-1} has a seeding cost of $674.04 per ha^{-1}

[t]Cereal Rye (Wrens Abruzzi var.) drilled at 50 kg/ha^{-1} plus Crimson Clover (Dixie var.) drilled at 14 kg/ha^{-1} has a management cost of $266.97 per ha^{-1}.

[s]Cereal Rye (Wrens Abruzzi var.) drilled at 101 kg/ha^{-1} has a management cost of $320.46 per ha^{-1}.

persisting high temperatures during plant development. The medium and high cotton seeding rates resulted in higher profits ($4,806 and $4,787 ha^{-1}, respectively) than the low seeding rate ($4,309 ha^{-1}).

When evaluating revenue across the three growing seasons, no significant differences were observed among cover crops and associated seeding rates. However, numerically higher profits of cover crop and cotton seeding rate arrangement was associated with cereal rye at medium cotton seeding rate generating $4,906 ha^{-1}. Another profitable combination was the mixture of cereal rye and crimson clover with cotton seeded at the highest rate with respective profit of $4,905 ha^{-1}. For crimson clover or cereal rye cover crops, the medium or high cotton seeding rates generated numerically higher profits compared to the low seeding rate. Thus, to increase revenue, at least the medium seeding rate should be considered over the low seeding rate. Because these economic analyses included the 2019 growing season during which severe drought occurred, overall net profits from this 3-year experiment were decreased compared to a typical growing season with optimum weather conditions and adequate rainfall amounts.

SUMMARY

In general, cotton ERI varied among three growing seasons with an overall average ERI of 9.0 without differences among cover crops. Across three growing seasons, cotton population at each seeding rate was not different with respect to cover crops and was consistently related to cotton seeding rates. The seed cotton yield averaged over 3 years produced 3,767 kg ha^{-1} and was not dependent on cover crop type. However, yield was lower for lower cotton seeding rates, compared to medium and high seeding rates. Differences in seed cotton yield were observed among years with lower yield in 2019 due to a prolonged drought, compared to higher average yield of 4,597 kg ha^{-1} in 2018 and 2020. Overall, the cover crop type did not significantly affect seedling emergence and final stand, which is often a concern for farmers adopting no-till growing methods. Profitability was more related to seeding rate at which producers should consider planting at a standard rate in a no-till system with cover crops. Future studies should examine yields at several different seeding rates between medium and high seeding rates to obtain more yield data so no-till cotton producers can decide which rate generates the most optimal returns. For cover crop selection, producers might consider the lowest cost of cover crop.

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DISCLAIMER

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