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AGRONOMY AND SOILS

Impact of Cover Crop Species on Soil Physical Properties, Cotton Yield, and Profitability

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ABSTRACT

Poor soil health purportedly limits crop yield and on-farm profitability in environments with a history of intensive tillage. Research was conducted to determine if cover cropping improves basic soil physical properties, crop productivity, and economic parameters in conventionally tilled soils. The effects of irrigation and cover crop species on bulk density, water infiltration rate, cotton yield, and net returns were evaluated on a Dundee silty clay loam (Fine-silty, mixed, active, thermic type Typic Endoqualfs) near Tribbett, MS in 2017 and a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) near Starkville, MS from 2017 through 2018. Relative to the fallow production system, cereal rye and crimson clover decreased bulk density 4.6% but had no effect on water infiltration rate. Pooled over year and location, cover crop had no effect on lint yield in either irrigated or non-irrigated environments. However, transitioning from conventional to a cover crop system reduced net returns for cotton $50.22/ha to $307.87/ha on average. Our data indicate that while transitioning from a conventional to a fall cover crop production system, modest improvements in some soil physical properties due to cover crop establishment will not increase cotton productivity but will decrease net returns.

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In the Mid-South, conventional tillage is a common practice for cotton (*Gossypium hirsutum* L.) production systems. After cotton harvest, land commonly remains fallow during the winter until planting the following season. Fallow fields are at greater risk for erosion and nutrient leaching because of the lack of plant roots, and high rainfall occurring during the winter months. Cover crops are a relatively simple solution to this problem. Cover crops are defined as any living ground cover grown between the harvest and planting of a cash crop (Hartwig and Ammon, 2002). Cover crops are grown when land would otherwise be fallow and increases the amount of time that plant roots are in the ground – reducing the risk of erosion and nutrient loss to leaching. In recent years, there has been a resurgence in the popularity of cover crops in agriculture. Reasoning for implementation of cover crops in agricultural systems vary. Producers are encouraged to plant cover crop species due to monetary benefits from government agencies, lease agreements that require the planting of a cover crop, or simply from the desire to improve soil health.

The benefits of cover crops are widely known and well-discussed in the literature. Cover crops provide many benefits including: reduced soil erosion, weed suppression, improved soil fertility and soil quality, improved water quality and/or diversification of insect populations (Blanco-Canqui et al., 2015; Hartwig and Ammon, 2002; SARE, 2012). However, no single cover crop species provides all the benefits listed above (Chu et al., 2017). Therefore, it is important to consider the desired effect of a cover crop and choose cover crop species accordingly. For example, if soil erosion is a problem, a high biomass cover crop species such as wheat (*Triticum aestivum* L.) or cereal rye (*Secale cereal* L.) may help reduce erosion (SARE, 2012). It is common for more than one cover crop species to be planted simultaneously. Although this increases seed cost, the producer may receive multiple benefits from multiple species that a single cover crop species would not provide, such as reduction in erosion from high biomass species and N-fixing benefits from legume cover crop species (Chu et al., 2017; Lewis et al., 2018; NRCS, 2015). However, other data suggests that multi-species cover crops had no benefit in terms of yield or economic return (Lewis et al., 2018)

Much of the previous research on soil health benefits from cover crops has been conducted in no-till or conservation tillage systems (Basche et al., 2016; Parvin et al., 2004). In areas of the Cotton Belt, particularly the Mississippi Delta, these tillage systems are not commonplace due to the use of beds which are utilized to facilitate drainage and furrow irrigation. Furrow irrigation, although the least efficient method of irrigation, is commonly utilized in the Mississippi Delta and requires raised beds (FAO, 2018).

Improvements in soil water holding capacity have been reported due to cover crop use. In a no-till system with a cereal rye cover crop, Basche et al. (2016) observed a 10% increase in soil water content when measured at field capacity when cover crops were planted compared to a non-cover crop system. They also reported a cereal rye cover crop system increased plant available water by at least 21% in comparison to a non-cover crop system. Chu et al. (2017) reported increased gravimetric soil moisture content where multiple species cover crop blends were utilized in comparison to single-species and no cover crop plots. Cover crops also increase the amount of time before runoff occurs (Krutz et al., 2009; Locke et al., 2015).

Water infiltration is affected by soil crusting along with other soil properties (Folorunso et al., 1992). Soil crusting decreases water infiltration as soil aggregates are disrupted when rainfall or irrigation water come into contact with the soil (Folorunso et al., 1992). Cover crop residue decreases the amount of crusting by providing a barrier that reduces the amount of energy produced by raindrops as they impact the soil surface (Moldenhauer and Kemper, 1969).

Water infiltration rates as affected by cover crops has been well researched. Again, most of this research was conducted in no-till or conservation tillage systems. Locke et al. (2013) observed that water infiltration rate in cotton production systems in the crop row was improved when a clover (*Trifolium* sp.) cover crop was planted (0.14 – 0.15 cm min^{-1}) compared to a rye cover crop (0.06 – 0.08 cm min^{-1}) and when no cover crop was planted (0.03 – 0.08 cm min^{-1}). However, no differences in infiltration rate due to cover crop were observed in the furrow (between the crop rows). Nouri et al. (2019) found that cover crop species had no effect on initial or cumulative water infiltration rate in conventional till systems. However, in no-till systems, vetch and wheat cover crops increased initial and cumulative water infiltration rate compared to where no cover crop was utilized. Cover crops have also been reported to decrease soil bulk density. Haruna and Nkongolo (2015) observed a 3.5% decrease in soil bulk density from cereal rye cover crops vs non-cover cropped plots in corn/soybean rotation systems.

Increasing world population requires improved crop productivity on fewer farmland hectares. Improving soil health parameters and subsequent productivity is important for producers, and cover crops have been shown to improve soil health parameters in no-till or conservation tillage systems. However, research is lacking regarding cover crop benefits following fall conventional tillage systems. Therefore, research was conducted to evaluate the effect of cover crop species on soil water infiltration and bulk density in a conventional tillage system under irrigated and rainfed systems and the subsequent impact on cotton growth, development, yield, and net returns.

MATERIALS AND METHODS

Research was conducted at the R.R. Foil Plant Science Research Center on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) near Starkville, MS in 2017 and 2018 and at the Delta Research and Extension Center on a Dundee silty clay loam (Fine-silty, mixed, active, thermic type Typic Endoqualfs) near Tribbett, MS in 2017. Experimental units were four 97-cm spaced rows in Starkville and four 102-cm spaced rows in Tribbett, both 12 m in length. Treatments were implemented in a split-plot arrangement within a randomized complete block design with four replications. The whole-plot factor was irrigation consisting of a fully irrigated or rainfed treatment. Irrigation was delivered by 38-cm by 9-mil flat-lay polyethylene tubing (Delta Plastics, Little Rock, AR) to every furrow in irrigated plots when the average soil moisture potential in the rooting zone reached -100 kPa as measured by Watermark® soil moisture sensors (Irrometer, Riverside, CA). Watermark® soil moisture sensors were installed at the edge of the bed in the second replication of each location at depths of 15, 30, 60, and 90 cm and data were collected from these sensors two times each week (Plumblee et al., 2019).

Approximately 12.5 centimeters of water were applied per hectare at each irrigation event. Irrigation events occurred on 31 July 2017 and 25 July 2018 in Starkville and 26 June 2017, 10 July 2017, and 03 August 2017 in Tribbett.

The sub-plot factor was cover crop species which included cereal rye, crimson clover (*Trifolium incarnatum* L.), oat (*Avena sativa* L.), and cereal rye + crimson clover. Cover crops were seeded with hand spreaders at 56, 11, 56, and 50 + 6 kg ha^{-1}, respectively (Table 1). A winter fallow treatment was included for comparison in each replication.

Prior to cover crop seeding, fields were disked, and beds were formed using a pan style bedding implement. Following cover crop planting, beds were rolled down in preparation for cash crop planting the following spring (Table 1). No additional tillage operations were performed until after crop harvest each fall. Cover crops were terminated using glyphosate (Roundup PowerMAX, Monsanto Company, St. Louis, MO) at a rate of 1.5 kg ae ha^{-1} on dates given in Table 1. An additional application of glufosinate (Liberty 280 SL, Bayer CropScience, Research Triangle Park, NC) at a rate of 0.6 kg ai ha^{-1} was made immediately after cotton planting to crimson clover and cereal rye + crimson clover plots as they contained living plant material. No disease or insect issues were observed immediately after crop emergence

PhytoGen 444 WRF (Dow Agrosciences, Indianapolis, IN) was seeded at a rate of 111,150 seeds ha^{-1} at a depth of 2.5 cm with a John Deere MaxEmerge XP planter (Deere and Co., Moline, IL) equipped with floating row cleaners (Martin-Till, Elkton, KY), Keeton Seed Firmers (Precision Planting, Tremont, IL) and cast iron, pinch-style closing wheels (Deere and Co., Moline, IL) (Table 1). Fertility, pest management, plant growth regulator, and harvest aids were managed based on Mississippi State University Extension recommendations. Seed were treated by the manufacturer with azoxystrobin, fludioxanil, imidalcloprid, mefenoxam, myclobutanil, and sedaxane (TRiO™ seed treatment). Nitrogen in the form of 32% UAN was injected 7.5 cm deep in a split application of 112 kg N ha^{-1} in Tribbett and 134 kg N ha^{-1} in Starkville. Half of each total N rate was applied just after planting and at pinhead square (~35 days after planting). Cotton harvest aids were applied when cotton reached 60% open boll with a second application made 10 days after the first application. The center two rows of each plot were harvested using a spindle picker modified for small plot research (Table 1).

Water infiltration readings were taken from traffic furrows, non-traffic furrows, and on top of the bed from experimental units in three replications at each location. Water infiltration data were collected on the following dates: 08 August 2017 and 14 August 2018 in Starkville and 29 September 2017 in Tribbett. Dates were selected based upon similar volumetric water content at the time of sampling. Single-ring infiltrometers, 31 cm in diameter and 25 cm tall, were utilized to measure water infiltration (Bouwer, 1986). Infiltrometers were placed 5 cm in the ground and filled with water utilizing a falling head approach. Infiltration measurements were taken over a period of 12 hours to determine the rate at which water infiltrated into the soil and water was added to each ring to a known level as needed. Each ring contained incremental graduations above the soil surface from which water infiltration rate in a known area were calculated. Soil samples were collected when infiltration measurements were taken to determine the volumetric water content of the soil. Soil cores used to calculate volumetric water content were 5.5 cm in diameter and 6.0 cm in height. Samples were weighed immediately following collection and placed in a forced air dryer at 60°C for 72 hours. Samples were then weighed again and volumetric water content at the time of collection was determined. Volumetric water content in Starkville in 2017, Starkville 2018, and Stoneville 2017 was 6.5%, 6.5%, and 5.9%, respectively.

Table 1. Planting and termination dates for cover crop treatments and planting and harvest dates for cotton for a study conducted from 2017 through 2018 on Leeper silty clay loam and Dundee silty clay loam soil textures near Starkville, MS and Tribbett, MS, respectively.

Environment	Cover Crop		Cotton	
	Planting Date	Termination Date	Planting Date	Harvest Date
Starkville 2017	18 Nov. 2016	13 April 2017	08 May 2017	10 Nov. 2017
Starkville 2018	17 Nov. 2017	01 May 2018	10 May 2018	10 Oct. 2018
Tribbett 2017	22 Nov. 2016	10 May 2017	26 May 2017	25 Oct. 2017

Bulk density measurements were collected from traffic furrows, non-traffic furrows, and on top of the bed from all four replications at each location (Blake and Hartge, 1986). Bulk density data were collected on the following dates: 08 August 2017, and 14 August 2018 in Starkville, and 29 September 2017 in Tribbett. Brass rings, 5.5 cm in diameter and 6.0 cm tall, were placed in the soil and subsequently removed with soil inside. Rings and cores were placed in a forced air dryer for 72 hours at 60°C to remove moisture and then weighed to determine bulk density.

Data were analyzed in SAS (v. 9.4, SAS Institute Inc., Cary, NC) using the PROC MIXED procedure. All data beyond 2.5 σ of the mean for a given variable were removed as outliers. No differences due to experimental location were observed, thus data were pooled across experimental location. Data were subjected to analysis of variance and means were separated using Fisher's Protected LSD at $\alpha = 0.05$.

When evaluating the net returns of cover cropping compared to a fallow system, only costs that varied between treatments were included. Therefore, only the additional costs associated with planting and termination of cover crops were considered. Seed costs for all four cover crop programs were obtained from Nutrien Ag Solutions, located in Leland, Mississippi. Cereal rye, crimson clover, oat, and cereal rye + crimson clover had seed costs of $34.57/ha, $26.19/ha, $44.45/ha, and $45.43/ha, respectively. Planting costs, irrigation costs, and termination costs were obtained from the Mississippi State University 2020 Delta planning budget (Mississippi State University, 2020). Planting costs, assuming a broadcast application with a Cyclone Spin unit were $23.47/ha and include the total direct and fixed costs for planting. These costs vary as applicator and tractor size vary, but the sizes used closely represent the typical planting practice in the Mississippi Delta region. Results did not change when considering various applicator and tractor sizes. Irrigation costs were $183.59/ha for the Starkville locations and $211.69/ha for the Tribbett location. Irrigation costs contain the cost of the roll-out pipe, labor, diesel fuel, and repair and maintenance costs. The difference in irrigation costs between locations is due to the greater amount of water applied at the Tribbett location. Cover crop termination costs include the additional cost of herbicide and application not found in a fallow system. Herbicide costs were $10.37/ha for Liberty 280 SL. Application cost was $17.30/ha and assumed air application. The Roundup Powermax that was applied to terminate the cover crops was also used as a burndown in the fallow system to remove any living plant material. Therefore, it is not included in the termination costs as this cost does not vary across treatments. In total, additional termination costs were $27.67/ha for crimson clover and cereal rye + crimson clover due to the added application of glufosinate. A full list of these costs can be found in Table 2. Cotton seed price, $0.23/kg, and lint price, $1.70/kg, were based on the average Mississippi price from 2010-2018 from USDA NASS data (USDA, 2020).

RESULTS AND DISCUSSION

Bulk Density. A primary hypothesis of this research was that sampling location or irrigation level, in a cotton production system with a fall cover crop would result in reduced soil bulk density relative to winter-fallow. In both irrigated and non-irrigated environments, crimson clover or cereal rye cover crops reduced bulk density (data were pooled over sample collection location) up to 4.6% relative to that of the fallow control ($p < 0.0490$) (Table 3). Conversely, independent of irrigation level or sampling location, neither oats nor a crimson clover/cereal rye mixture altered bulk density. These data indicate that some but not all cover crops can decrease bulk density in the traffic furrow, non-traffic furrow, and planting bed in both irrigated and non-irrigated environments.

Table 2. Additional costs associated with cover cropping and irrigation for cereal rye (Secale cereale L.), crimson clover (Trifolium incarnatum L.), oat (Avena sativa L.), and cereal rye + crimson clover $/ha.

Crop	Seed Cost[z]	Planting Cost[y]	Herbicide Costs[y]	Custom Spray[y]	Total Cover Cropping Cost	Irrigation Costs at Starkville[y]	Irrigation Costs at Tribbett[y]
Cereal Rye	34.57	23.47	0.00	0.00	58.04	183.59	211.69
Crimson Clover	26.19	23.47	10.37	17.30	77.33	183.59	211.69
Oats	44.45	23.47	0.00	0.00	67.92	183.59	211.69
Cereal Rye + Crimson Clover	45.43	23.47	10.37	17.30	96.58	183.59	211.69

[z] Cover crop seed cost retrieved from Nutrien Ag Solutions, Leland, MS in 2020.

[y] Costs retrieved from 2020 Mississippi State University Department of Agricultural Economics Budget Report 2019-01. https://www.agecon.msstate.edu/whatwedo/budgets/docs/20/MSUCOT20.pdf Accessed: 05 May 2020.

Table 3. Analysis of variance for irrigation, cover crop, and sampling location on bulk density (g cm^{-3}) and water infiltration (cm min^{-1}) measurements for a study conducted from 2017 through 2018 on Leeper silty clay loam and Dundee silty clay loam soil textures near Starkville, MS and Tribbett, MS, respectively.

Treatment	Bulk Density	Infiltration
Cover Crop Species	-------------------- g cm^{-3} --------------------	------------------ cm min^{-1} ------------------
Crimson Clover	1.24 (0.069)^z b^y	0.70 (0.429)
Oats	1.27 (0.069) ab	0.68 (0.429)
Cereal Rye	1.24 (0.069) b	0.83 (0.436)
Cereal Rye + Crimson Clover	1.28 (0.069) ab	0.81 (0.429)
Fallow	1.30 (0.069) a	0.58 (0.429)
Irrigation		
Rainfed	1.26 (0.068)	0.74 (0.419)
Irrigated	1.27 (0.068)	0.71 (0.419)
Location		
Traffic Furrow	1.31 (0.068) a	0.37 (0.424) b
Non-Traffic Furrow	1.24 (0.068) b	0.36 (0.423) b
Planting Bed	1.22 (0.068) c	1.43 (0.421) a
Effect	-- P value	--
Cover Crop (CC)	*	NS
Irrigation (I)	NS	NS
CC X I	NS	NS
Location^x (L)	**	**
CC X L	NS	NS
I X L	NS	NS
CC X I X L	NS	NS

^{z} Standard error

^{y} Means followed by the same letter within each column are not significantly different

^{x} Location in experimental unit of where measurement was taken (traffic furrow, non-traffic furrow, or on top of planting bed)

*, ** denotes significance at the 0.05 and 0.001 probability level, respectively

Relative to fall fallow, the inclusion of a cover crop in cotton production systems typically has no effect or slightly increases bulk density, regardless of cover crop species evaluated, tillage system employed, or time since transitioning from a fall fallow system (Balkcom et al., 2013; Locke et al., 2013, 2015; Mbuthia et al., 2015; Nouri et al., 2019; Raper et al., 2000; Sainju et al., 2005, 2006, 2008, 2010; Schwab et al., 2002; Veenstra et al., 2007). Several cover crop species have been evaluated for impact on bulk density in cotton production systems including rye, wheat, and vetch (*Vicia* sp.) mixtures. Utilization of cover crops increased soil bulk density 14% in a clay loam managed under conservation tillage (Veenstra et al., 2007). However, under standard tillage practices, utilization of cover crops had no effect on bulk density at depths of 0 cm to 15 cm. While Haruna and Nkongolo (2015) observed a 3.5% decrease in soil bulk density from cereal rye cover crops vs non-cover cropped plots in corn/soybean rotation systems, we can find no other reports of a cover crop decreasing bulk density in cotton production systems. The effect of cover crops on bulk density has been evaluated in several conventional (Nouri et al., 2019; Sainju et al., 2008, 2010; Veenstra et al., 2007) and reduced tillage systems (Locke et al., 2013, 2015) including ridged and non-ridged soils with or without deep tillage (Balkcom et al., 2013), fall or spring para tillage (Balkcom et al., 2013; Schwab et al., 2002), chisel tillage (Sainju et al., 2005, 2006), mulch tillage (Sainju et al., 2008, 2010), strip tillage (Balkcom et al., 2013; Sainju et al., 2005, 2006; Schwab et al., 2002; Veenstra et al., 2007), and no-tillage (Balkcom et al., 2013; Mbuthia et al., 2015; Nouri et al., 2019; Raper et al., 2000; Sainju et al., 2005, 2006, 2008, 2010). Within a given tillage system, the inclusion of a cover crop in a cotton production system never improved bulk density, even when evaluated 34 years after transitioning from fall fallow (Mbuthia et al., 2015; Nouri et al., 2019). Thus, regardless of tillage practice, preferred fall cover crop, or time since transitioning from a fall fallow production system, the effect of cover crop on bulk density will likely be minimal in the US cotton belt.

Water Infiltration Rate. Another hypothesis of this research was that cover crops increase water infiltration rate in both irrigated and non-irrigated environments, regardless of sampling location. Infiltration rate varied as expected among sampling locations, that is, infiltration on top of planting bed > non-traffic furrow = traffic furrow (Table 3) ($p < 0.0001$). However, contrary to our primary hypothesis, cover crop had no effect on infiltration during the two-year period in which cover crops were utilized, regardless of sampling location or irrigation level ($p \geq 0.1620$). These data indicate that it is unlikely for a cover crop to improve water infiltration rate during the early phases of converting from a fall fallow to a fall cover crop production system.

While our results displayed no impact of cover crops on water infiltration rate, existing literature indicates that cover crops can improve infiltration in soils common to the US cotton belt. These differences in results speak to the complex nature of cover crops and subsequent impacts on soils. In addition, the effect of cover crops on water infiltration will likely depend on type of tillage system utilized, time since establishment of the cover crop production system, and time-of-the year when the water infiltration rate estimate is determined. Locke et al. (2013) noted that after six years of cotton production, there was no effect of a cereal rye or a balsamic clover cover crop (*Trifolium repens* L.) on water infiltration rate in a silt loam soil under reduced tillage and no-tillage management. Conversely, seven years after establishing a cereal rye cover crop, the steady-state infiltration rate when measured in the spring for a silt loam soil managed under reduced and no-tillage was at least 33% greater than that of the fall fallow cotton production system (Krutz et al., 2009). However, when water infiltration rate was measured in the fall, an interaction between cover crop and tillage system was evident (Locke et al., 2015). In the reduced tillage system, cover crop had no effect on water infiltration rate, while water infiltration rate in the no-tillage system with a cereal rye cover crop was 18.5% greater than that of the winter fallow, no-tillage system. They postulated that tillage and bed reconstitution during the fall minimized the effect of cover crop on infiltration in the reduced tillage system. The importance of a tillage by cover crop interaction on the effect on water infiltration rate is further evidenced by the work of Nouri et al. (2019). Thirty-four years after establishing conservation practices in a silt loam soil, the inclusion of either a vetch or a wheat cover crop in a cotton production system managed under no-tillage, increased cumulative infiltration 114% and 86%, respectively. Conversely, neither the vetch nor wheat cover cropped system improved cumulative infiltration when established in cotton production systems managed under conventional tillage. These data indicate that the inclusion of cover crops in cotton production systems can, after multiple years of maturation, improve water infiltration rate in reduced tillage systems. Once cover crop production systems mature, the effect on water infiltration rate within a given year will likely be stable in no-tillage systems but transient in reduced tillage systems due to bed reconstitution in the latter. If considering a cover crop system coupled with some form of tillage, potential impacts on water infiltration rate should not be the driving force behind cover crop adoption.

Cotton Lint Yield. We postulated that cover cropping would improve yield relative to fallow production systems due to enhanced soil health in the former. However, our data indicate that during the two-year period that the fall fallow production system was transitioning into a fall cover crop production system, cover crop had no effect on lint yield in either irrigated or rainfed environments ($p \geq 0.2257$) (Table 4). These data indicate that one should not expect a yield increase from the addition of commonly recommended cover crop species during the period that fall fallow production systems are transitioning to a fall cover crop production system in either irrigated or non-irrigated environments.

Table 4. Analysis of variance for irrigation and cover crop on cotton lint yield (kg ha^{-1}) for a study conducted from 2017 through 2018 on Leeper silty clay loam and Dundee silty clay loam soil textures near Starkville, MS and Tribbett, MS, respectively.

Treatment	Lint Yield
Cover Crop Species	------------- kg ha^{-1} -------------
Cereal Rye	1,068 (57.1)^{z}
Crimson Clover	1,111 (57.3)
Oat	1,119 (57.3)
Rye + Clover	1,063 (57.6)
Fallow	1,128 (57.1)
Irrigation	
Rainfed	1,075 (53.9) b^{y}
Irrigated	1,120 (53.9) a
Effect	
Cover Crop (CC)	NS
Irrigation	*
CC X Irrigation	NS

^{z} Standard error

^{y} Means followed by the same letter within each column are not significantly different

*, ** denotes significance at the 0.05 and 0.01 probability level, respectively.

Cover crops tend to have a nominal and inconsistent effect on cotton yield regardless of cover crop species, tillage system, or time since inception of best management practices. For example, thirty-four years after instituting conservation tillage and cover crop production systems in a silt loam soil, neither a vetch nor a wheat cover crop in conventional or no-tillage systems altered cotton yields relative to fall fallow (Nouri et al., 2019). In other cases, the effect of cover crop on cotton yield varied between years and among the tillage by cover crop production systems evaluated (Sainju et al., 2006). In the inaugural year of a cotton/grain sorghum (*Sorghum bicolor* L.) rotation, inclusion of a cereal rye, hairy vetch (*Vicia villosa* Roth), or a hairy vetch/cereal rye cover crop in a silt loam soil managed under conventional tillage either maintained or reduced cotton yield up to 28% relative to fall fallow. Under strip-tillage, regardless of the species or mixture evaluated, cover crops increased cotton yield by at least 17%. In the no-tillage system, only cereal rye improved cotton yields relative to fall fallow. Ironically, in year three, there was no effect of cover crop on lint yield regardless of tillage system. We surmise, therefore, that it is highly unlikely that cover crops will consistently improve cotton yield in the US cotton belt, regardless of species or mixture founded, tillage system evaluated, or time since adoption of management practices that promote soil health.

Net Returns to Cover Cropping. Net returns were examined for all four cover crops compared to a fallow system for both an irrigated and non-irrigated system. For irrigated cotton, net returns were revenue net the costs of cover cropping and irrigation. Under irrigation, the fallow system had higher net returns than the four cover crop systems at $2445/ha on average across all site years. The next highest net returns were observed with the oat system at $2394/ha, which was $51/ha less than the fallow system. The cereal rye + crimson clover system had the lowest net returns at an average of $2136/ha. This was partially due to the higher costs associated with this system. Lastly, cereal rye and crimson clover cover cropping systems averaged net returns of $2247/ha and $2232/ha, respectively. The full results of revenue, costs, and net returns, including results by site-year, for irrigated cotton can be found in Table 5.

When examining results for irrigated cotton for each individual site-year, results were mostly similar. The major difference being oats provided the greatest net returns at the Starkville location in 2017 at $2718/ha, which was $112/ha higher than the fallow system. However, net returns in an oat cover crop system were lower than the fallow system by $158/ha at Starkville in 2018 and $104/ha at Tribbett in 2017. The crimson clover cover crop system did produce slightly higher net returns than the fallow system in Starkville in 2017 by $2.08/ha. However, net returns for the crimson clover system were $244/ha and $395/ha less than the fallow system in Starkville in 2018 and Tribbett in 2017, respectively. The net returns for the crimson clover were the lowest of any treatment at Tribbett in 2017. The cereal rye + crimson clover had the lowest net returns at Starkville in 2017 and Starkville in 2018.

For non-irrigated cotton, net returns were the revenue net the additional costs of cover cropping. In this non-irrigated system, the fallow system again had the highest average net returns across all site-years at $2561/ha. Crimson clover cover cropping systems produced the second highest net returns at $2484/ha, followed by cereal rye at $2367/ha. Cereal rye + crimson clover and oats cover cropping systems produced the lowest net returns at $2225/ha and $2329/ha, respectively. Net returns of non-irrigated plots were higher than that of irrigated due to the fixed costs of irrigation and the amount of rainfall reducing the need for irrigation. The full results of net returns for non-irrigated cotton can be found in Table 6.

Table 5. Average net returns for irrigated cotton across site years for cereal rye (*Secale cereale L.*), crimson clover (*Trifolium incarnatum L.*), oat (*Avena sativa L.*), and cereal rye + crimson clover, and winter fallow.

Cover Crop	Revenue[z] ($/ha)	Costs[y] ($/ha)	Net Returns ($/ha)
Starkville 2017			
Cereal Rye	$2,700.64	$241.63	$2,459.01
Crimson Clover	$2,869.44	$260.92	$2,608.52
Oats	$2,969.84	$251.51	$2,718.33
Cereal Rye + Crimson Clover	$2,593.42	$280.16	$2,313.25
Fallow	$2,790.03	$183.59	$2,606.44
Starkville 2018			
Cereal Rye	$2,557.15	$241.63	$2,315.52
Crimson Clover	$2,562.67	$260.92	$2,301.75
Oats	$2,638.95	$251.51	$2,387.44
Cereal Rye + Crimson Clover	$2,553.32	$280.16	$2,273.15
Fallow	$2,729.42	$183.59	$2,545.83
Tribbett 2017			
Cereal Rye	$2,237.27	$269.73	$1,967.54
Crimson Clover	$2,074.76	$289.02	$1,785.73
Oats	$2,356.58	$279.61	$2,076.98
Cereal Rye + Crimson Clover	$2,131.67	$308.26	$1,823.40
Fallow	$2,392.85	$211.69	$2,181.16
All			
Cereal Rye	$2,498.35	$251.00	$2,247.36
Crimson Clover	$2,502.29	$270.29	$2,232.00
Oats	$2,655.12	$260.87	$2,394.25
Cereal Rye + Crimson Clover	$2,426.13	$289.53	$2,136.60
Fallow	$2,637.43	$192.96	$2,444.48

[z] Revenue given average cottonseed and lint prices from 2010 – 2018. Retrieved from USDA National Agricultural Statistics Service Quick Stats. https://quickstats.nass.usda.gov/ Accessed: 05 May 2020.

[y] Total cost of cover cropping and irrigation. Cover crop seed costs retrieved from Nutrien Ag Solutions, Leland, MS in 2020. Equipment, planting, termination, and irrigation costs retrieved from 2020 Mississippi State University Department of Agricultural Economics Budget Report 2019-01. https://www.agecon.msstate.edu/whatwedo/budgets/docs/20/MSUCOT20.pdf Accessed: 05 May 2020.

As with the results of the irrigated cotton, net returns to cover cropping are highly variable from one site-year to another. The fallow system had the highest net returns at Starkville in 2018 and Tribbett in 2017, with cereal rye having the highest in Starkville in 2017. At the Tribbett location, cereal rye cover cropping system produced the lowest net returns at $2232/ha, which was $333/ha less than net returns in the fallow system. Cereal rye + crimson clover cover crop systems produced the lowest net returns at the Starkville location in 2017 and the Starkville location in 2018 at $2428/ha and $1758/ha, respectively.

The costs associated with cover cropping present a significant obstacle to profitability. The combination of seed produced and sold as well as lint yield, at prices of $0.23/kg and $1.70/kg, respectively, needed to cover these costs for each cover crop can be found in Table 7. Cereal rye + crimson clover would require the highest yields to pay for cover cropping due to the high costs associated that system. It would take additional seed yield of 142 kg/ha and lint yield of 54 kg/ha to cover the associated costs for this system. Due to cereal rye having the lowest costs to implement, it would take an additional 98 kg/ha of seed and 37 kg/ha of lint to cover the additional cover cropping costs. An oats system would require yield of 109 kg/ha and 41 kg/ha for seed and lint, respectively, to cover implementation costs. Lastly, a crimson clover system would require 120 kg/ha of seed and 46 kg/ha of lint to cover the cover cropping costs. These yields can be considered as the yield above a fallow system needed for cover cropping to break-even.

Table 6. Average net returns for non-irrigated cotton across site years for cereal rye (*Secale cereale L.*), crimson clover (*Trifolium incarnatum L.*), oat (*Avena sativa L.*), cereal rye + crimson clover, and winter fallow.

Cover Crop	Revenue[z] ($/ha)	Costs[y] ($/ha)	Net Returns ($/ha)
Starkville 2017			
Cereal Rye	$2,922.51	$58.04	$2,864.47
Crimson Clover	$2,914.98	$77.33	$2,837.64
Oats	$2,587.25	$67.92	$2,519.33
Cereal Rye + Crimson Clover	$2,524.30	$96.57	$2,427.73
Fallow	$2,851.61	$0.00	$2,851.61
Starkville 2018			
Cereal Rye	$2,061.59	$58.04	$2,003.55
Crimson Clover	$2,328.34	$77.33	$2,251.01
Oats	$2,173.25	$67.92	$2,105.33
Cereal Rye + Crimson Clover	$1,854.08	$96.57	$1,757.50
Fallow	$2,266.71	$0.00	$2,266.71
Tribbett 2017			
Cereal Rye	$2,290.23	$58.04	$2,232.19
Crimson Clover	$2,440.83	$77.33	$2,363.50
Oats	$2,431.44	$67.92	$2,363.52
Cereal Rye + Crimson Clover	$2,587.61	$96.57	$2,491.04
Fallow	$2,565.29	$0.00	$2,565.29
All			
Cereal Rye	$2,424.78	$58.04	$2,366.74
Crimson Clover	$2,561.38	$77.33	$2,484.05
Oats	$2,397.31	$67.92	$2,329.40
Cereal Rye + Crimson Clover	$2,322.00	$96.57	$2,225.42
Fallow	$2,561.20	$0.00	$2,561.20

[z] Revenue given average seed cotton and lint prices from 2010 – 2018. Retrieved from USDA National Agricultural Statistics Service Quick Stats. https://quickstats.nass.usda.gov/ Accessed: 05 May 2020.

[y] Total cost of cover cropping and irrigation. Costs retrieved from 2020 Mississippi State University Department of Agricultural Economics Budget Report 2019-01. https://www.agecon.msstate.edu/whatwedo/budgets/docs/20/MSUCOT20.pdf Accessed: 05 May 2020.

Table 7. Seed and lint yield, at prices of $0.23/kg and $1.70/kg[z], needed to cover costs of cover cropping for cereal rye (*Secale cereale L.*), crimson clover (*Trifolium incarnatum L.*), oat (*Avena sativa L.*), and cereal rye + crimson clover.

Cover Crop	Cover Cropping Costs[y]	Seed yield	Lint yield[x]
	($/ha)	(kg/ha)	
Cereal Rye	85.92	98.09	37.27
Crimson Clover	105.21	120.11	45.64
Oats	95.80	109.36	41.56
Cereal Rye + Crimson Clover	124.46	142.07	53.99

[z] Average prices from 2010 – 2018. Retrieved from USDA National Agricultural Statistics Service Quick Stats. https://quickstats.nass.usda.gov/ Accessed: 05 May 2020.

[y] Total cost of cover cropping. Equipment cost retrieved from 2020 Mississippi State University Department of Agricultural Economics Budget Report 2019-01. https://www.agecon.msstate.edu/whatwedo/budgets/docs/20/MSUCOT20.pdf Accessed: 05 May 2020. Cover crop seed cost retrieved from Nutrien Ag Solutions, Leland, MS.

[x] Assumes a ratio of seed to lint yield of 1:0.38.

However, on average, this study did not find statistically significant yield increases, and in some cases, yield decreased under cover cropping. This, combined with higher costs, decreases the viability of cover cropping. Large increases in yield and/or decreases in herbicide, pesticide, and irrigation costs are needed in order for cover cropping to be profitable. The combination of a lack of consistent yield increases and higher costs under cover cropping resulted in lower net returns, on average, for all cover crops examined in this study compared to a fallow system.

CONCLUSION

The objective of this research was to determine if cover crops improve basic soil physical properties, cotton productivity, and net returns in conventionally tilled soils. Our data indicate that some fall cover crop species, including cereal rye and crimson clover, decrease bulk density up to 4.6% relative to a fallow production system. However, cover crop had no effect on water infiltration rate in the seed bed, traffic, or non-traffic furrow in either irrigated or rainfed environments. Moreover, while transitioning from a conventional, fall fallow production system to a fall cover crop production system, cover crop had no effect on cotton lint or seed yield in either rainfed or irrigated environments. These data indicate that cover crops can improve some basic soil physical properties related to soil health, but the modest gains afforded by some species of fall cover crops does not improve cotton yield during the early years of transitioning from a fall fallow to a fall cover crop cotton production system. This resulted in a decrease in net returns on average when a cover crop system was implemented.

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