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Effects of Nitrogen Rate and Cover Crop on Cotton (*Gossypium hirsutum* L.) Yield and Soil Water Content

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Abstract: The objective of this study was to test the effects of N rates and tillage radish (*Raphanus sativus* var. *longipinnatus*) cover crop (TRCC) on soil water and cotton (*Gossypium hirsutum* L.) yield. In three years of the investigation, the treatments were N rates at 84 kg ha^{-1} and 140 kg ha^{-1} with and without TRCC. Soil water contents were measured using soil water sensors. Results showed that cotton yield was not significantly ($p > 0.05$) influenced by TRCC. Compared to N rate at 84 kg ha^{-1}, 140 kg N ha^{-1} increased lint yield by 2.0%, 7.4%, 18.4% in 2017, 2018, and 2019, respectively, but the increase was significant only in 2019 ($p < 0.02$). Interactions between TRCC and nitrogen rate on yield were significant ($p < 0.03$) only in 2017. TRCC increased soil water infiltration capacity, resulting in higher soil water content. Use of TRCC did not affect the cotton yield, which could be due to the high inputs of water and high rates of N neutralizing the positive contributions to the cotton growth expected from the TRCC. Sub-optimum winter temperatures hampered the establishment and subsequent growth of TRCC, which also possibly contributed to its minimum impacts on cotton crop performance in the following season.

Keywords: cotton; nitrogen; tillage radish; cover crop; yield

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1. Introduction

The United States of America, the largest cotton exporter, accounting for one-third of global trade in raw cotton, is the third largest cotton producer in the world [1]. The U.S. cotton is grown in a region known as the Cotton Belt in the Southern United States, including the State of Mississippi. Mississippi producers planted approximately 287,000 hectares of cotton in 2019 in Mississippi, which make Mississippi the third largest state in the United State in cotton production [1]. Most of the cotton produced in the State of Mississippi is grown in the Mississippi Delta (MD).

Nitrogen (N) fertilization in cotton has a critical effect on cotton yield [2,3]. Both under-use and over-use of N fertilizer can create a negative effect on the desired growth pattern of cotton plants and compromise yield [4–6]. A N deficiency can cause poor vegetative growth, fruit shedding, and small bolls resulting in low yield [7]. But N in excess of the cotton plant demands can induce excessive vegetative growth, increase pest problems, delay maturity, and ultimately reduce the crop yield [8–10]. Most of N fertilizer in cotton production is applied by broadcasting on the soil surface or directly injecting into the soil. Soil physical, chemical, and biological properties and climatic conditions could influence N cycling processes in the soil and further affect the cotton growth response to N fertilization [5]. Due to the complexity of interactions among the chemical, physical, and biological factors in soil-N cycling processes, it is very difficult to accurately predict N application requirements of cotton crops [5,11]. Consequently, researchers have been continuously investigating the crop response to N rate for optimal N-use efficiency in cotton production systems [12].

In the MD region, mean annual precipitation is about 130 cm. About 70% of the precipitation is received during the crop-fallow months of September through March, but the staple crops (soybean, cotton, corn, and rice) are summer grown (April–August). Traditionally, for controlling weeds and avoiding heavy rainfalls in April/May, tillage operations are performed following harvest in the fall season [13]. This practice makes the soil vulnerable to water and wind erosion during the fallow months, modifying rainwater infiltration, runoff, and deep percolation processes and culminating in poor rainwater use efficiency in cropping systems, which leads to more irrigation water withdrawal from the shallow Mississippi River Valley Alluvial Aquifer underlying this region [14].

Depending on the amount and distribution of the rainfall events, cover crops during the fallow season can improve water infiltration and reduce runoff losses of the rainwater received [15–18]. Fallow season-long cover crops can also improve crop yields and be beneficial for soil health [19]. Water extraction by the cover crops, however, can also limit the water left in the soil for the subsequent crop, especially in water limited areas. But, in the humid climate of the MD characterized by heavy rainfalls during the winter-crop-fallow season, unlike in the arid and semiarid climates, the water used by the cover crops normally does not affect the water availability to summer crops that follow.

Tillage radish (*Raphanus sativus* var. *longipinnatus*) has been adopted as a cover crop by farmers for over a decade in the United States. The large and deep taproot of this crop can penetrate compacted soil layers by "bio-drilling" the crop root zone, which increases water infiltration into the soil, reduces surface runoff, and supports the subsequent crop by obtaining water and nutrient from deep soils [20,21]. Because of its robust rooting system and rapid growth characteristics, tillage radish cover crop (TRCC) can scavenge for the residual N, deeper than normal, in the soil, which can reduce excess N leaching into the groundwater [20].

In the MD, heavy rainfall events occur frequently, causing extensive amounts of runoff water loss from croplands. Excessive surface runoff is often associated with lower rainwater infiltration into the soil for crop use and excessive nutrients leached out of the cropped areas leading to water-soil-environmental quality degradations [22–24]. Optimizing N application rates and minimizing excess N leaching from crop production systems can help maximize farm profits and minimize environmental impacts. The objective of this study is to assess interacting effects of N rates and TRCC system on cotton yield and soil water in the humid climate of the MD.

2. Materials and Methods

2.1. Experimental Site Description

Field studies were conducted from 2017 to 2019 in a USDA-ARS research farm at Stoneville, MS. The farm is located about 15 km east of the Mississippi River in the MD region. The field was approximately 5 ha in rectangular shape (183 × 276 m^2) with an approximately 0.5% slope from the east to the west and constituted one-half of the area under a center pivot irrigation system installed at the site for sprinkler irrigations. A weather station was located at the west edge of the field, outside the center pivot sprinkler reach. According to the USDA NRCS soil survey [25], predominant soil map unit in the field was Commerce very fine sandy loam (Cn; fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts). Smaller areas of Commerce silty clay loam (Ch; fine-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) and Bosket very fine sandy soils (Be; Fine-loamy, mixed, active, thermic Mollic Hapludalfs) were located in the southwest and northwest corners, and southeast corner of the field, respectively.

Twelve plots were laid out in the field (Figure 1). Plots were 183 m long, 23 m wide, each with 24 rows spaced at 0.97 m. A 7.7-m wide buffer was used between the plots. A 2 × 2 factorial experiment in randomized complete block design (RCBD) with three replications was used to test the effect of two N application rates (84 kg ha^{-1} and 140 kg ha^{-1}) with cover crop (CC) and with no cover crop (NCC) on cotton yield. The four treatments CC × N84 (84 kg ha^{-1} N rate with CC), NCC × N84 (84 kg ha^{-1} N rate with no cover crop), CC × N140 (140 kg ha^{-1} N rate with CC), and NCC × N140 (140 kg ha^{-1} N rate with no cover crop) were randomly assigned to each of the three blocks to give a total of 12 plots in the test.

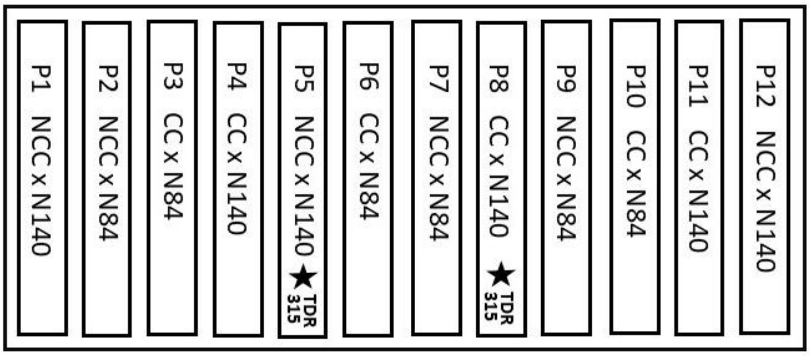

Figure 1. Experimental plot layout with RCBD; Block 1 (P1–P4); Block 2 (P5–P8); Block 3 (P9–P12). Soil water sensing devices (TDR-315) were installed in P5 and P8 for measuring soil volumetric water content. Associated with each soil water sensing system in P5 and P8, four soil water sensors (TDR 315) were installed at depths of 15, 30, 46, and 61 cm.

2.2. Crop Management

The field study was conducted for three consecutive crop years from 2017 to 2019. After cotton was harvested each year, cotton stalks were shredded using a rotary shredder. Then the tillage radish cover crop (TRCC) was planted at a seeding rate of 9 kg ha^{-1} using a seed drill. In the fall 2016 (the winter cover crop season before the first cotton crop in 2017), the cover crop was sowed on 12 October and 25 mm water was applied after planting. However, due to the unusual dry weather, the seeds did not geminate well. The TRCC was replanted on 20 October and 19 mm water was applied for gemination. The CC was terminated on 17 March 2017. For 2018 cotton season, the TRCC was planted on 27 October 2017 and terminated on 22 March 2018. In 2017 and 2018, the cover crop was terminated by applying glyphosate herbicide and using minimum-tillage practice which lightly disked the soil to chop cover crop residue, followed by forming the rows for planting. In the 2019 cotton season, the TRCC was planted on 25 October 2018. The TRCC was killed by the colder than typical winter weather, so no herbicide was sprayed for cover crop termination in 2019. In all three years, no nitrogen fertilizer was applied to the cover crop.

Cotton variety FM1944GLB2 was planted in 2017 and 2018 seasons, and the variety ST4848GLT in 2019. Because the variety FM1944GLB2 was not available in our cottonseed vendor in 2019, we chose the variety ST4848GLT for planting in that year as its field trials reported near identical agronomic performance related to lint yield and lint value (https://wharton.agrilife.org/2018/12/11/2018-replicated-agronomic-cotton-evaluation-race-south-east-and-central-regions-of-texas/ accessed on: 9 July 2021). The planting dates were on 9 May 2017, 10 May 2018, and 17 May 2019. The seeding rate was approximately 11.3 seeds m^{-2} on raised beds in a furrow-ridge system with 0.97 m row spacing. N fertilizer was applied as a urea-ammonium nitrate solution (N-sol, 32% N) to the plots at 23 days after planting (DAP) in 2017, 52 DAP in 2018, and 55 DAP in 2019. A professional consultant was hired to work on the insect and weed control of the study field. Based on the recommended insect and weed control guidelines for Mississippi [26–28], the consultant regularly assessed the insect and weed situation in the study field and cooperated with our technicians to promptly apply insecticides and herbicides as needed. In general, insects and weeds in the study field were well controlled for all three seasons.

In 2017, cotton canopy defoliation was initiated on 12 September. Central rows of each plot were harvested for determining the yield on 3 October. In 2018, the cotton was defoliated twice. The first defoliation was on 14 September and the second on 28 September. Cotton in the central rows of each plot was picked on 11 October followed by planting the cover crop on 25 October. In 2019, the defoliation was conducted on 20 September. Because of the wet weather, cotton harvest was delayed until 18 November. Same as the previous two years, the central 8 rows in each plot were picked for yield. The TRCC was planted on 21 November. In all three years, the cotton was picked using a CASE IH spindle-type cotton harvester.

2.3. Soil Water

A Valley 8000 center pivot (Valmont Irrigation, Valley, NE, USA) irrigation system was employed for irrigation. The system was configured in four spans with a total length of 233 m. The distance from the sprinklers to the ground surface was approximately 1.83 m. Soil volumetric water contents (VWC) in the CC and NCC plots were measured with soil water sensors. The sensors (TDR 315, Acclima, Meridian, ID, USA) were installed at depths of 15, 30, 46, and 61 cm. A data logger was set up for each sensor to measure and record hourly VWC at each depth. Soil VWC measurements at the four depths were interpreted using a weighted-average method to reflect the soil water conditions across the plant root zone [29]. The weight assigned to the sensor depth of 15, 30, 46, and 61 cm was 0.3, 0.25, 0.25, and 0.2, respectively. The weighted-average VWC was used to determine the soil water depletion. An irrigation was generally triggered as the percentage of plant available water (PPAW) dropped to approximately 50%. Using the weighted-average VWC, soil field capacity (FC), and permanent wilting point (PWP), the PPAW is defined as follows Equation (1):

$$\text{PPAW}\ (\%) = \frac{(\text{Weighted\_average VWC}) - (\text{VWC at PWP})}{(\text{VWC at FC}) - (\text{VWC at PWP})} \times 100\% \quad (1)$$

In irrigation scheduling, crop growth stage and short-time weather forecast were given consideration along with sensor-measured soil water contents. No irrigation was conducted in 2017 and 2019 due to sufficient precipitation in the summer. In 2018, 25 mm water was applied on 16 May after planting for better germination, and another 114 mm water was applied in six irrigation events from June to August with 19 mm depth of water in each irrigation to avoid runoff.

2.4. Data Collection and Analysis

In the three years, seed-cotton picked from the central rows of each plot were weighed for yield using a load cell weighing system installed on a cotton boll buggy. In 2017 and 2018, approximately 45 kg samples of seed-cotton were randomly collected from each plot during harvest and these samples were ginned using the micro-gin in USDA-ARS Cotton Ginning Research Unit for the lint turnout. In 2019, about 4 kg seed-cotton samples were randomly collected from each plot and ginned using a small saw-gin in USDA-ARS Crop Genetics Research Unit for lint turnout. Lint yield for each year was calculated using the area harvested, seed-cotton weight, and lint turnout. Soil water content variation in a CC plot and NCC plot for three years was recorded and processed for evaluating the impact of TRCC on soil water.

Proc ANOVA procedure of SAS (SAS Institute Inc., Cary, NC, USA) was used to determine the effect of N rate, CC, and N rate × CC on lint yield. Mean separation tests were performed at $p = 0.05$ level using the PLM and Tukey's procedures of SAS.

3. Results and Discussion

3.1. Cover Crop

TRCC grew very well in spring 2017 (Figure 2). The average TRCC height was about 60 cm. On average, the radish taproot was about 25 cm long and 5 cm in diameter. In 2018 and 2019, the cover crop did not grow as well as in 2017. The stalks were about 15–20 cm tall and the roots were about 10 cm long and 2 cm in diameter. One of the reasons for the poor growth of TRCC in these two seasons was that it suffered severe cold winter weather, which seriously damaged the plants and limited their growth in the subsequent spring seasons.

Figure 2. Tillage Radish cover crop in 2016–2017 winter season. Left: Biomass above ground surface and the root below ground surface. Right: Decomposed roots after the crop was killed for planting cotton.

As stated above, depending on the prior season cotton crop harvest, the TRCC was first planted on 12 October and replanted on 20 October in 2016, on 27 October in 2017, and on 25 October in 2018 for affecting cotton growth in 2017–2019 seasons, respectively. Figure 3 shows the air temperature variation, precipitation, and solar radiation from 2016 to 2019. The weather in the winters of 2017 and 2018 was colder and had more precipitation than the winter of 2016. From 1 October 2016 to 31 March 2017 there were 19 days with a temperature <0 °C with a minimum temperature (T_{min}) of −9.4 °C, and total precipitation was 608 mm. However, from 1 October 2017 to 31 March 2018 there were 44 days with a temperature <0 °C with a T_{min} of −13.3 °C, and total precipitation was 838 mm. From 1 October 2018 to 31 March 2019, the number of days with a temperature <0 °C was 33 while the T_{min} was −3.9 °C. Although the T_{min} in 2019 winter was higher compared to the winter in 2017 and 2018, the total precipitation was 1071 mm, which was much greater than that in the same period of the other two years.

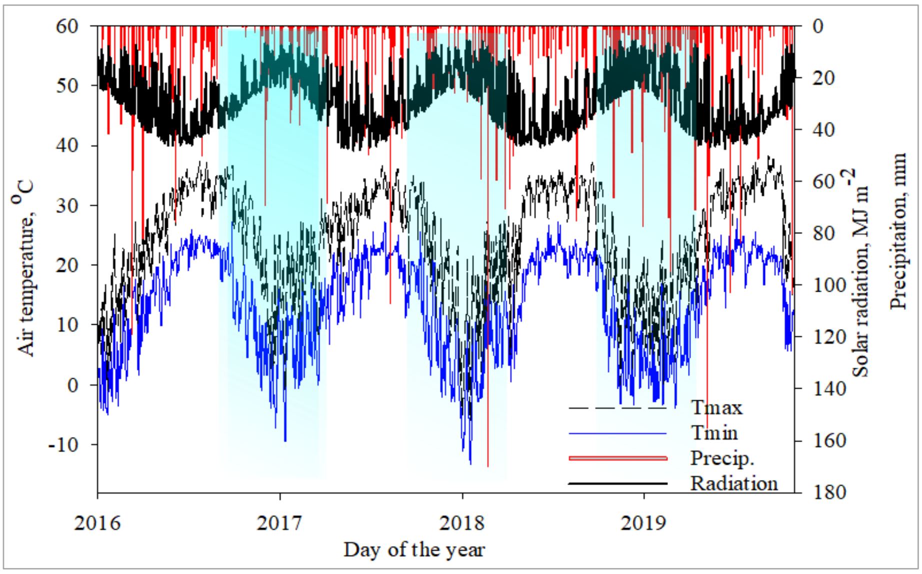

Figure 3. Daily maximum and minimum air temperatures, precipitation, and solar radiation from 1 January 2016 to 31 December 2019. Highlighted days are from 1 October to 31 March of each year in which TRCC grew.

The earlier planting and subsequent mild weather helped in the establishment of the cover crop before severe winter set in for 2016, but the later plantings followed by severe winter in 2017 and 2018 severely restricted the establishment of the TRCC before winter started and its subsequent growth in the following springs. What we learned was that the TRCC should be planted no later than the middle of October to allow the plant to be well developed prior to the cold winter weather for its optimum regrowth in the subsequent spring. From the observed TRCC growth in 2016–2017 season, it is clear that a well-developed TRCC can survive the winter weather and grow fast in the following spring for optimum biomass, both above and underground (Figure 2). Further investigations for determining an optimum planting window and cutoff date for establishing TRCC in the climate of the MD regions is needed and will be taken up in subsequent studies.

3.2. Soil Water

The prime reason for choosing tillage radish as a cover crop was that TRCC can produce a large taproot swollen with carbohydrates and penetrate compacted soil to provide better soil tilth for cotton crop root growth in the following season (Figure 2). Such long and swollen roots filled with carbohydrates and other N containing metabolites, once killed in the spring season for planting cotton, can improve the soil fertility [30]. Furthermore, as the metabolites in the roots decompose, many holes left behind from the large taproots in the soil will allow more rainwater to infiltrate into the soil, which increases the soil water available for the cotton plant [20]. Cotton plants have a root system that can reach the water stored in deep soil profile [31]. It was hypothesized that the TRCC during the winter season that preceded the cotton season could possibly increase soil water availability for cotton root uptake, thereby reducing the need for supplemental irrigation for the crop [32]. Depending on the amount and distribution of the rainfall events, cover crops during the fallow season can improve water infiltration and reduce evapotranspiration and runoff losses [15–17].

We examined the soil water changes during the cotton growth season (summer) that can be attributed to the TRCC grown in the plots during the preceding winter season. Some increases in soil water content under cotton due to the TRCC were evident (Figure 4). Soil water content in plot 8 with TRCC was higher than soil water contents in plot 5 without TRCC consistently during the three cotton growth seasons (2017–2019). In Figure 4, the higher soil water content in plot 8 could be due to the increase of rainwater infiltration by TRCC of the soil and enhanced soil physical properties for retaining more water in the soil profile. Further investigations are needed for ascertaining the exact reason for the observed changes in water contents in the soil profile. The soil water content difference between the TRCC plot and the NCC plot was more pronounced in 2017 than similar effects measured in 2018 and 2019. This could be due to poor growth of the TRCC in these two years and resultant inability of these less-grown roots in generating significant increase in water infiltration to impact the soil water content.

Figure 4. Soil water content variation in Plot 5 and Plot 8 during cotton growth season in 2017–2019. Plot 5 had no cover crop while Plot 8 had cover crop. Both plots had the same nitrogen application rate of 140 kg ha^{-1}.

3.3. Cotton Lint Yield

Lint yield response to cover crop and N rate for the three-year trial are given in Tables 1 and 2. Cotton yield advantages from winter cover crops are expected in irrigated cotton production systems in the Southeast US regions [33]. ANOVA results indicated that in 2017 the effects of TRCC and N rate on lint yield were not significant, however, the effect of the interaction, CC × N rate on lint yield was significant (p = 0.0344) (Table 1). Treatment CC × N140 recorded the highest lint yield of 1328 kg ha^{-1}, which was significantly higher than the yield obtained in the treatment CC × N84 (p = 0.0240) and NCC × N140 (p = 0.0201) (Table 2). Although it was not statistically different, the yield in N140 was slightly higher than that in plots of N84, and yield in CC was slightly higher than that in NCC (Table 2).

Table 1. ANOVA summary for lint yield response to cover crop and nitrogen application rates.

Year	Source	DF	Mean Square	F Value	Pr > F
2017	Cover Crop	1	2408	2.39	0.1607
	N rate	1	1925	1.91	0.2042
	Cover Crop × N rate	1	6533	6.48	0.0344
2018	Cover Crop	1	9690	0.69	0.4309
	N rate	1	32137	2.28	0.1694
	Cover Crop × N rate	1	3234	0.23	0.6447
2019	Cover Crop	1	31416	2.75	0.1361
	N rate	1	90828	7.94	0.0226
	Cover Crop × N rate	1	4563	0.4	0.5453

N = nitrogen; DF = degree of freedom; Pr = probability; F = Fisher statistic.

Table 2. Lint yield means (kg ha^{-1}) and mean comparison of various treatments.

Effect	Comparison	2017		2018		2019	
		Mean *	SD	Mean	SD	Mean	SD
CC	CC–NCC	1292 [e]	54	1429 [e]	100	983 [e]	148
NCC		1264 [e]	20	1486 [e]	140	1085 [e]	124
N84	N84–N140	1266 [e]	27	1405 [e]	118	947 [a]	123
N140		1291 [e]	52	1509 [e]	105	1121 [b]	102
CC × N84	CC × N84–CC × N140	1256 [a]	39	1393 [e]	109	876 [e]	137
CC × N140		1328 [b]	43	1464 [e]	97	1089 [e]	45
NCC × N84	NCC × N84–NCC × N140	1275 [e]	9	1417 [e]	151	1018 [e]	61
NCC × N140		1253 [e]	23	1554 [e]	111	1153 [e]	145
CC × N84	CC × N84–NCC × N84	1256 [e]	39	1393 [e]	109	876 [e]	137
NCC × N84		1275 [e]	9	1417 [e]	151	1018 [e]	61
CC × N140	CC × N140–NCC × N140	1328 [c]	43	1464 [e]	97	1089 [e]	45
NCC × N140		1253 [d]	23	1554 [e]	111	1153 [e]	145

* Means with different letters (a, b, c, d, e) of same comparison in same column are significantly different ($p < 0.05$). N = nitrogen; CC = cover crop; NCC = no cover crop; SD = standard deviation.

In 2018, effect of N rate, cover crop, and CC × N rate on yield was not significant, with p values of 0.4309, 0.1694, and 0.6447, respectively (Table 1). NCC × N140 had the maximum yield of 1554 kg ha^{-1}, and CC × N84 had the minimum yield of 1393 kg ha^{-1} (Table 2). Yield in NCC was 57 kg ha^{-1} higher than in CC, and the yield in N140 was 104 kg ha^{-1} higher than in N84. Although no significant effect of cover crop and N rate on yield was observed in 2018, the results showed that N application rate of 140 kg ha^{-1} increased the yield while cover crop reduced the yield (Table 2).

In 2019, the ANOVA indicated that effect of N rate on lint yield was significant (p = 0.0226) while the effects of CC (p = 0.1361) and CC × N rate (p = 0.5453) on lint yield were not (Table 1). Lint yield in N140 was significantly higher than in N84 ($p < 0.05$) (Table 2). The yield in NCC was 10.4% higher than CC while the yield of CC × N140 was

24.3% higher than the yield of CC × N84. However, these differences were not statistically significant ($p > 0.05$) (Table 2). In a no-till system in Alabama, Southeast USA, cotton yield following rye (*Secale cereale* L.) cover crop was significantly higher than crimson clover used as cover crop [33]. Cotton lint yield following a wheat (*Triticum aestivum* L.) also increased significantly [34]. Their studies showed the importance of choosing the right cover crop suited for the climate and soil of the location for tapping the positive benefits of cover crop on cotton yields. Results of our three-year trial indicated that TRCC did not significantly enhance cotton yields in the humid climate of the Mississippi Delta. This could be due to the high inputs of water (Figure 3; rainfall and irrigations) and high rates of N neutralizing the positive contributions to cotton growth expected from the cover crops in these aspects in the trials. Sub-optimum winter temperatures hampered the establishment and subsequent growth of the cover crop, possibly contributing to its minimum impacts on cotton crop performance in the following season (Figure 3).

Increasing N rate from 84 to 140 kg ha^{-1} increased the yield by 2%, 7.4%, and 18.4% in 2017, 2018, and 2019, respectively. Farmer-received cotton lint price was 1.51 USD kg^{-1}, 1.55 USD kg^{-1}, and 1.29 USD kg^{-1} in 2017, 2018, and 2019, respectively [35]. Using the cotton price and N cost in each year, economic gain by increasing the N rate was calculated to be 103 USD ha^{-1} and 166 USD ha^{-1} in 2018 and 2019, respectively. However, the gain was negative 20 USD ha^{-1} in 2017 due to small yield increase. The net profit increase not only depended on the increase of yield, but also the price of cotton and N fertilizer in each year. For example, the cotton price decreased 17% from 2018 to 2019 while the N price increased 7%, which generate substantial influence on the net profit offered by the increase of N rate.

In general, the 3-year results showed that, compared to N rate of 84 kg ha^{-1}, the N rate of 140 kg ha^{-1} could increase lint yield while the cover crop could decrease the lint yield. However, yield response to cover crop and N rate in 2017 did not follow that trend well. In 2017, CC treatment had a higher yield than NCC while it was reversed in both 2018 and 2019 season. Prior to 2017, this field was used for another study on N fertilization in cotton. The yield responding differently in 2017 could be caused by the N residual left in the field in the previous season, which was picked up by the TRCC and grew well to its potential as indicated by the significant results in cover crop by N rate interaction ($p < 0.0344$) (Table 1). The residual N unused by the previous crop and left in the soil was available for use by the TRCC in fall of 2016 and spring of 2017. The healthy TRCC (Figure 2) scavenged the residual N [20], which allowed cotton yield in 2017 to respond to the additional N applied. The stunted TRCC in the other two years did not use as much residual nitrogen, possibly resulting in the non-significant effect of CC x N rate on lint yield in 2018 ($p = 0.6447$) and 2019 ($p = 0.5453$) (Table 1).

4. Conclusions

Response of cotton yield and soil water content to nitrogen application rates and tillage radish cover crop (TRCC) in cotton was investigated. Results showed that the TRCC had no significant effect on cotton yield. Increasing N rate from 84 kg ha^{-1} to 140 kg ha^{-1} increased cotton yield in one out of three years in the experiments. Interaction between cover crop and nitrogen rate on cotton yield was significant only in one out of the three years. Our study indicated that TRCC increased soil water infiltration capacity and benefited the soil to retain higher soil water content. Increasing N rate from 84 kg ha^{-1} to 140 kg ha^{-1} could possibly increase cotton yield but needs further investigations to confirm. The non-significant impact of TRCC on cotton yield could be caused by poor growth of TRCC from cold temperatures and excessive winter rains.

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