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Impact of Cover Crop and Soil Apparent Electrical Conductivity on Cotton Development and Yield

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Abstract.
Cotton is one of the major crops in the New Madrid Seismic Zone (NMSZ) of the U.S. Lower Mississippi River Valley region. Soils in the region are generally quite variable, with areas of very high sand content, and low soil organic matter levels are common. While cotton is a relatively low residue crop that can lead to reduced soil health over time, including winter cover crops can provide additional organic material that can help to improve and stabilize soil health. A study of soil health and irrigated cotton production began at the Fisher Delta Research, Extension and Education Center in Portageville, MO, USA, in 2019 with the operating hypothesis that reduced tillage and cover crops will improve soil health indicators in cotton production systems. The objective of this study was to evaluate effects of cover crops and reduced tillage on cotton crop growth and productivity in spatially variable soils. Three treatments included conventional tillage without a cover crop (CONV), conservation tillage without a cover crop (CONS), and conservation tillage with a winter cover crop (COVER). While rainfall was less in 2021 than in 2020, the study was irrigated, which would minimize any effects of drought stress. The COVER treatment yield was significantly lower than CONV at the median soil apparent electrical conductivity (EC_a) level in 2021, which could indicate the yield drag many producers report when first adopting cover crops. The CONV treatment had the most soil disturbance due to the bed preparation just before planting and showed the greatest impact of EC_a variation for both normalized difference vegetation index (NDVI) and yield. The COVER treatment showed the least impact of EC_a variation for both NDVI and yield. The study is continuing.

Keywords.
cotton, soil apparent electrical conductivity, precision agriculture, soil health

Introduction

Cotton is one of the major crops in the New Madrid Seismic Zone (NMSZ) of the U.S. Lower Mississippi River Valley region. Soils in the region are generally quite variable, with areas of very high sand content, and low soil organic matter levels are common. While the benefits of crop rotation are well known, in the case of cotton, the ability to change crops is often limited by other factors. Unlike combines, which can be used on multiple crops, cotton pickers are a major investment and can only be used for cotton. The decision to start growing cotton (i.e., purchase picker(s)) or stop producing cotton (i.e., sell picker(s) or leave them idle) requires careful consideration and is not generally a year-to-year decision. While cotton is a relatively low residue crop that can lead to reduced soil health over time, including winter cover crops can provide additional organic material that can help to improve and stabilize soil health.

Mobile measurements of apparent soil electrical conductivity (EC_a) have become widely used to map soil variability because EC_a responds to a number of important soil properties, and mobile measurements are relatively quick and inexpensive. In non-saline soils, most of the variation in EC_a is a function of soil texture, moisture content, bulk density and cation exchange capacity (CEC) (Corwin and Lesch 2005). In general, for non-saline soils, a decrease in EC_a indicates an increase in sand content, while an increase in EC_a indicates an increase in clay content. However, because the EC_a response with depth is nonlinear (Dualem 2014), the EC_a associated with sand at one depth in the profile is not the same as for sand at a different depth. Samples collected from the field and analyzed for texture can be used to relate texture and EC_a in a field.

Canopy reflectance can be used for estimating factors related to crop growth in the field, including the dimensionless crop coefficient, K_c. Hunsaker et al. (2005) used canopy reflectance to estimate K_c for cotton in the desert southwestern U.S. Vories and Jones (2015) conducted a comparison of normalized difference vegetation index (NDVI), which is calculated from canopy reflectance, among 31 varieties enrolled in the Missouri cotton Official Variety Test (OVT) in 2014. They observed significant differences in NDVI among varieties in silt loam fields with adequate rainfall.

Long-term conservation tillage and crop management practices can affect water quality and soil health, as well as crop yield productivity. A variety of studies have demonstrated benefits of reduced tillage including reduced soil erosion (Dabney et al. 2004), maintained or increased crop yields (Ehlers and Claupein 1994; Baumhardt and Jones 2002), and improved soil health (Veum et al. 2014). Diversified management practices, such as increased rotation diversity or addition of cover crops, also present an opportunity to enhance ecosystem function and biological diversity (Pimentel et al. 1992).

While much of the earlier work on tillage and cover crop effects has been done on a small-plot scale with fairly uniform soils, work is needed on large plots and spatially variable soils to more closely match the conditions faced by producers in the NMSZ and many other areas. A deeper understanding of the relationship between soil health measurements and cropping system productivity is necessary to identify the short-term and long-term benefits of conservation management for producers. The operating hypothesis of this project is that reduced tillage and cover crops will improve soil health indicators in cotton production systems. The objective of this study is to evaluate effects of cover crops and reduced tillage on cotton crop growth and productivity in spatially variable soils.

Methods and Materials

A study of soil health and cotton production began at the Fisher Delta Research, Extension and Education Center in Portageville, MO, USA, in 2019, on a center pivot irrigated field with primarily silt loam and sandy loam soils (Fig. 1a) that had been in continuous cotton since 2018. Weather data were collected from a nearby electronic station and hourly and daily summaries were placed on the University of Missouri Agricultural Electronic Bulletin Board (AgEBB; http://agebb.missouri.edu/weather/realtime/portageville.asp). Growing degree days (GDD) were calculated from a 15.6 ºC base as recommended for cotton. To provide higher resolution soil information, mobile EC_a data were collected on 17 June 2019 (Fig. 1b). The DUALEM-1HS system (Dualem, Milton, ON, Canada) provided simultaneous 0.3-, 0.5-, 0.8- and 1.6-m depths of exploration (DOE; the depth at which 70% of the cumulative response is obtained) (Dualem 2014). Data were collected on a 1-s interval at a 2.1 m s^{-1} overland speed and a 3.9-m transect spacing. Location of each data point was determined with the global navigation satellite system (GNSS), using an Ag Leader GPS 7500 receiver (Ag Leader Technology, Ames, IA, USA) with TerraStar-C Pro differential correction, with pass-to-pass accuracy of 30 – 60 mm (Ag Leader Technology 2019). To further investigate the soil textural variability, cores were collected at five locations and divided into six sections (0 – 76 mm, 76 – 229 mm, 229 – 381 mm, 381 – 533 mm, 533 – 686 mm, and 686 – 838 mm), with each section tested for the percentage of sand, silt and clay.

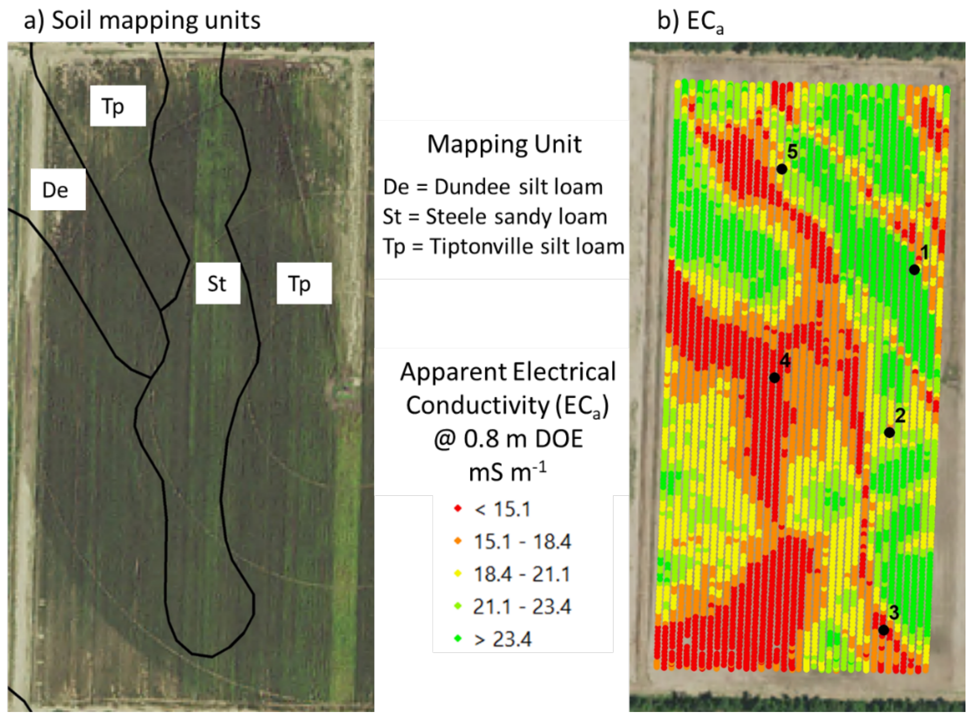

Figure 1. a) Aerial image of study field with overlaid soil mapping units and b) soil apparent electrical conductivity (EC_a) at a depth of exploration (DOE) of 0.8 m. The numbered points represent the locations of textural samples.

Yield data were collected from the conventionally managed field in 2019. The crop was harvested on 9 October with a Case IH 2155 cotton spindle picker (Case IH, Racine, WI, USA) equipped with an Ag Leader Insight yield monitor system with sensors for every row. The system included the Ag Leader GPS 7500 receiver described previously. The whole field was harvested at a 1.6 m s^{-1} overland speed. The yield monitor was calibrated by placing the cotton from each load in a boll buggy equipped with scales and a weight calibration specific to the test was developed. Additional details concerning yield monitor calibration were included in Vories et al. (2019). The boll buggy was built by Harrell Ag Products (Leesburg, GA, USA), with a weighing system added by Master Scales (Greenwood, MS, USA) in 2014. Known weights were placed in the unit each year before harvest to ensure the weighing system was working properly. The spatially-referenced yield data were obtained with the Ag Leader Technology program SMS Basic 19.50 (Fig. 2a).

In late 2019, treatment areas for five blocks of three treatments were selected. The treatments included conventional tillage without a cover crop (CONV), conservation tillage without a cover crop (CONS), and conservation tillage with a winter cover crop (COVER) (Fig. 2b). Plots were eight 0.97-m rows wide with length approximately 300 m. Treatments were arranged in a randomized complete block design with five blocks. To avoid confounding effects of irrigation and tillage, the area beyond the final drive tower of the center pivot system was not included. Because the fifth block of treatments was largely outside of the irrigated area, those plots were used for setting equipment and the data were not included in the study. A cereal rye cover was planted in the cover crop plots at approximately 100 kg ha^{-1} on 9 January and 16 November 2020.

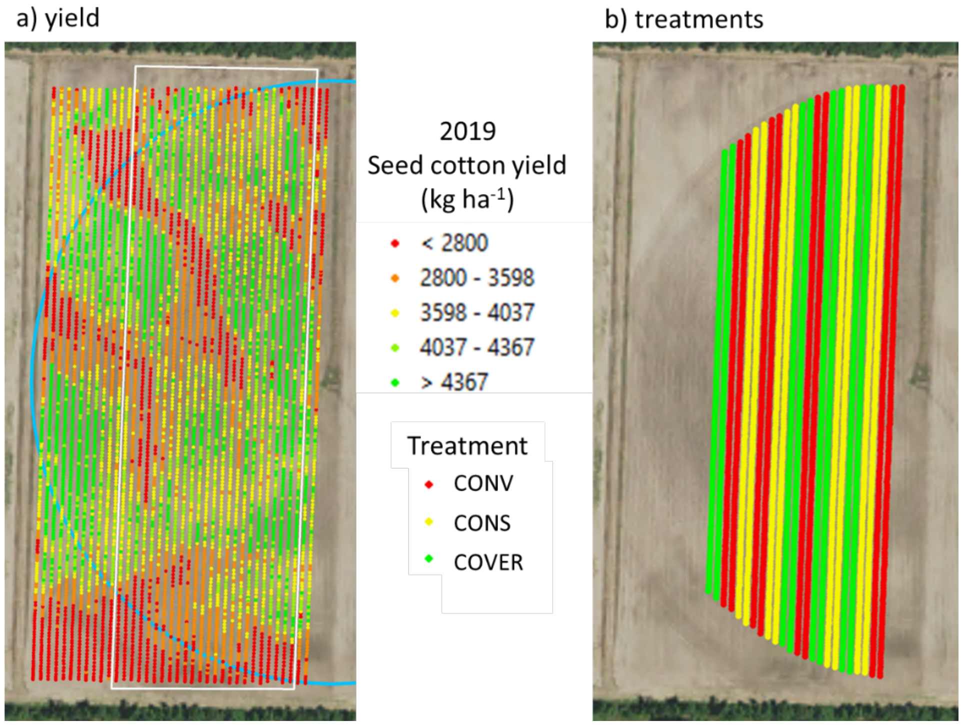

Figure 2. a) Seed cotton yield from the study field in 2019, the year before the study began. The white lines represent the study area. The blue semi-circle represents the track of the outermost center pivot track. b) The arrangement of tillage treatments conventional tillage without a cover crop (CONV), conservation tillage without a cover crop (CONS), and conservation tillage with a winter cover crop (COVER).

The field was planted at 10 seed m^{-1} with the cotton variety PHY 360 W3FE on 22 May 2020 and PHY 390 W3FE on 13 (CONV, CONS, study borders) and 14 (COVER) May 2021 using a John Deere (Moline, IL, USA) 1700 planter equipped with Precision Planting (Tremont, IL, USA) components. The conventional treatment was prepared for planting with a PrepMaster (Bigham, Lubbock, TX, USA), resulting in a weed-free and uniform bed surface. A row cleaner attachment to the planter was used to achieve a clean, uniform planting surface in the reduced tillage and cover crop plots, resulting in much less soil disturbance than the PrepMaster. The cover crop was not terminated before planting in either year.

The field was irrigated using a 160 m Valley 6000 center pivot irrigation system and irrigations were scheduled based on the Arkansas Irrigation Scheduler (Cahoon et al. 1990). Fertility was managed according to University of Missouri recommendations (Stevens 2019) and standard pest management recommendations for producing irrigated cotton in Missouri were followed (Bradley et al. 2015). Fertilizer, growth regulator, insecticide and harvest aids were applied as blanket treatments to the whole field. To the extent possible, the three treatments were managed for weed control independently based on observations of weed pressure. Spatially referenced yield data were collected on 22 October 2020 and 13 October 2021 using the system described earlier.

Differences in crop growth were observed throughout the field each year. Therefore, canopy reflectance and NDVI data were collected multiple times during each growing season using a Holland Scientific ACS-430 (Lincoln, NE, USA) sensor located 760 mm above each row of the crop canopy and pointing vertically downward.

To construct a data set containing both yield or NDVI and EC_a, the aggregating procedure described by Griffin et al. (2007) and Vories et al. (2020) was followed. The spatially referenced EC_a data developed from the EC_a survey described above was used along with the individual-row yield data, and all yield data points within 1.0 m of an EC_a data point were averaged. The 1.0 m radius around an EC_a data point was selected so that only the two nearest harvest rows to the EC_a data point were averaged.

The large, spatially referenced data sets were managed with ArcGIS for Desktop 10.4.1 (ESRI, Redlands, CA, USA) and spatial analysis of variance (SANOVA) was conducted using GeoDa 1.14.0 (Center for Spatial Data Science, Univ. of Chicago, Chicago, IL, USA) using the spatial error model as recommended for yield monitor data (Griffin et al. 2007). Tests of significance were conducted at the alpha = 5% level.

Results and Discussion

Weather

Figure 3 contains the cumulative rainfall and GDD from 1 May through 31 October for both years. While temperatures and thus GDD were similar for the two years, rainfall was different. Crops in the region can be negatively affected by both too much and too little rainfall; however, since this was an irrigated study, drought stress should have been minimal.

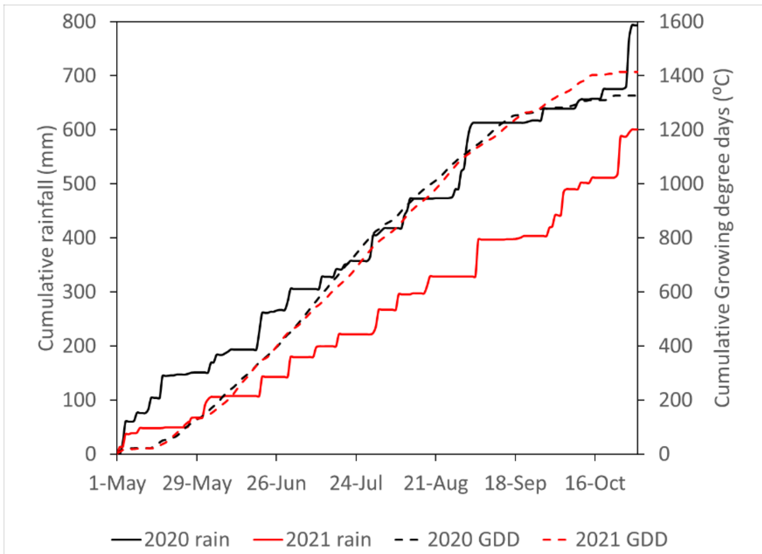

Figure 3. Cumulative rainfall and growing degree days (15.6 °C base) for the 2020 and 2021 cotton growing seasons.

Soil

Because most of the cotton roots in this soil are in the upper 0.8 m of the soil profile, EC_a at the 0.8 m DOE was used in all subsequent analyses. The EC_a levels in the whole field ranged from 3.9 to 31.3, with a mean of 19.4 mS m^{-1} (Fig. 1b). The soil texture varied greatly in both the horizontal and vertical directions, with sand contents of the individual samples ranging from 9 to 98%. (Table 1). Within the study plots (Fig. 2b) EC_a had a mean of 19.6 and a median of 19.7 mS m^{-1} and there were no significant differences in EC_a among the three treatments. When significant interactions are present in data, the level of the covariate will affect whether differences among treatments are significant; therefore, treatments in this report were compared at the study-area-median EC_a of 19.7 mS m^{-1}.

Growth

In 2020, the first monitoring date for NDVI was 14 July and most of the observed values were >0.80. However, even at those relatively high levels, significant differences were observed among the treatments when tested at the median EC_a value (Table 2). Furthermore, significant differences were observed among the interactions, or the rate of change in NDVI associated with a change in EC_a. Each of the values was positive, suggesting that as the sand content decreased, the plants were larger, which is consistent with visual observations. The CONV treatment, which had the most soil disturbance due to the bed preparation just before planting, showed the greatest impact of EC_a change, while the slopes of the CONS and COVER treatments were not significantly different from each other. Figure 4a shows how the treatment means were affected by EC_a, with CONV having the lowest NDVI of the three treatments at the lowest observed EC_a values (highest sand content) but having the highest NDVI at the highest observed EC_a values.

Table 1. Soil texture results for the five sample locations (Fig. 1).

Depth (mm)	Soil texture (%)		
	Clay (<0.002 mm)	Silt (0.002 – 0.05 mm)	Sand (0.05 – 2 mm)
Location 1			
0 – 76	16.0	46.7	37.3
76 – 229	21.8	53.8	24.4
229 – 381	28.7	62.6	8.7
381 – 533	23.2	47.9	28.9
533 – 686	18.2	48.8	33.0
686 – 838	19.3	51.4	29.3
Location 2			
0 – 76	9.3	23.0	67.7
76 – 229	15.2	34.6	50.2
229 – 381	26.3	59.2	14.5
381 – 533	25.1	61.2	13.7
533 – 686	28.6	60.9	10.5
686 – 838	31.1	57.6	11.3
Location 3			
0 – 76	4.2	5.3	90.5
76 – 229	3.1	7.4	89.5
229 – 381	2.7	3.0	94.3
381 – 533	2.4	3.8	93.8
533 – 686	20.3	53.5	26.2
686 – 838	22.2	59.0	18.8
Location 4			
0 – 76	4.6	19.0	76.4
76 – 229	4.3	13.5	82.2
229 – 381	2.8	8.9	88.3
381 – 533	0.9	1.1	98.0
533 – 686	0.9	1.1	98.0
686 – 838	-[z]	-	-
Location 5			
0 – 76	5.4	12.9	81.7
76 – 229	5.9	13.2	80.9
229 – 381	8.2	12.8	79.0
381 – 533	23.2	33.7	43.1
533 – 686	32.7	49.2	18.1
686 – 838	37.8	51.0	11.2

[z] sample not obtained

Table 2. Normalized difference vegetation index (NDVI) observed on the first monitoring dates of 2020 and 2021 at the median observed EC_a value (19.7 mS m^{-1})

Treatment	Normalized Difference Vegetation Index
15 July 2020	
Conventional (CONV)	0.835 b[z]
Conservation (CONS)	0.844 a
Cover crop (COVER)	0.807 c
EC_a interactions	
Conventional	0.0088 a
Conservation	0.0051 b
Cover crop	0.0037 b
24 June 2021	
Conventional (CONV)	0.504 a
Conservation (CONS)	0.502 a
Cover crop (COVER)	0.424 b
EC_a interactions	
Conventional	0.0037 a
Conservation	0.0010 ns
Cover crop	-0.0018 ns

[z] values of NDVI or interaction in a column within the same year and followed by the same letter are not significantly different at the alpha = 5 % level; ns interactions were not significantly different from 0

Based on the observations from 2020, NDVI monitoring started earlier in 2021, with the first date of June 24. As expected, the values were lower, and no significant difference was observed between the CONV and CONS treatment means. The COVER mean was significantly less than the other two, as it was in 2020. In addition, the interactions between EC_a and both CONS and COVER were not significantly different from 0, suggesting that the plant size was unchanged across changes in soil texture. The CONV treatment again showed a significant impact of EC_a change (Fig. 4b).

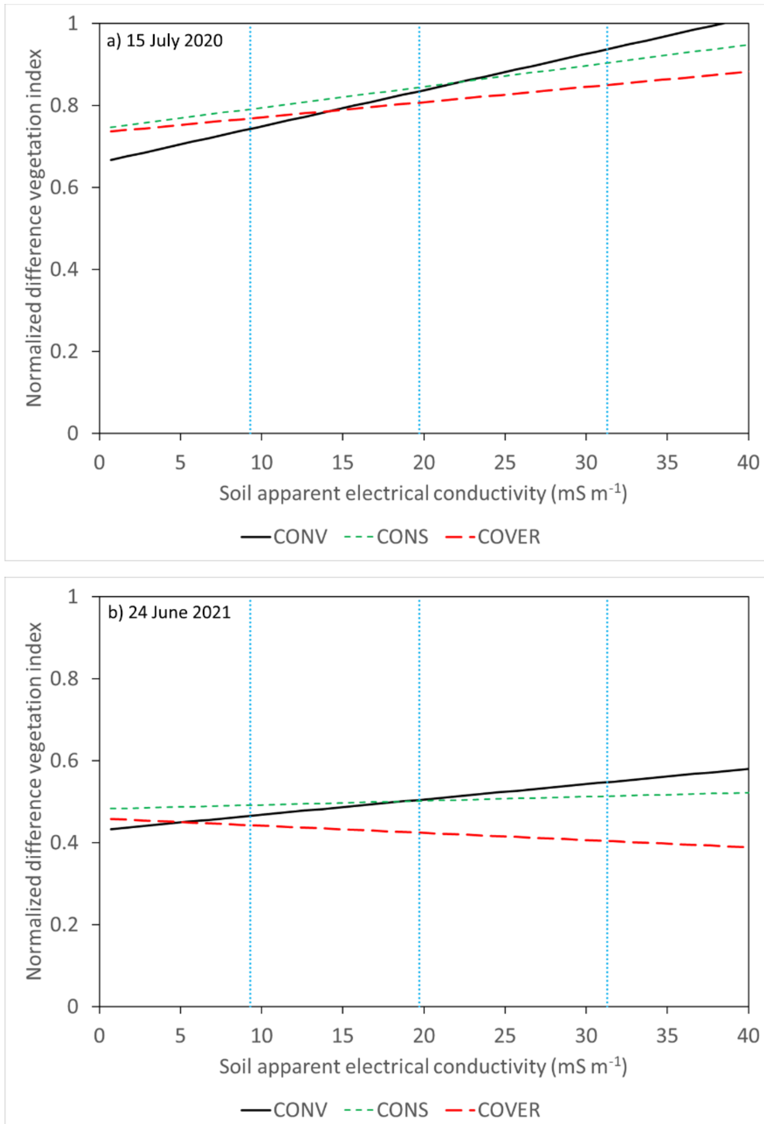

Figure 4. Relationship between NDVI and EC_a for measurements taken on a) 15 July 2020 and b) 24 June 2021. The vertical lines note the minimum, median, and maximum EC_a values observed in the study area

Yield

In 2020, the first year employing reduced tillage in both the CONS and COVER treatments and the first year following a cover crop in the COVER treatment, significant differences were observed in both the treatment means and the interactions with EC_a (Table 3). While the differences among the treatments were relatively small at the median EC_a value, they were greater at both lower values (more sand) and higher values (less sand) of EC_a (Fig. 5a). Similar to the NDVI in 2020, the CONV treatment showed the greatest impact of EC_a change.

Similar to NDVI (Table 2), the yields of the CONV and CONS treatments were not significantly different at the median EC_a value in 2021, while both were greater than the COVER treatment (Table 3). As observed in 2020 and for NDVI in both years (Table 2), the CONV was most impacted by EC_a, with a steeper slope in 2021 than 2020 (103 versus 81). The impact for the CONS treatment was also greater in 2021 than 2020 (60 versus 48). However, while the COVER treatment in 2020 was least impacted by changes in EC_a, the interaction with COVER was not significantly different from 0 in 2021. As noted in 2020, the differences among the treatments were greater at both lower values and higher values of EC_a (Fig. 5b).

Table 3. Seed cotton yield observed in 2020 and 2021 at the median observed EC_a value (19.7 mS m^{-1})

Treatment	Seed cotton yield (kg ha^{-1})
2020	
Conventional (CONV)	3473 b[z]
Conservation (CONS)	3592 a
Cover crop (COVER)	3558 ab
EC_a interactions	
Conventional	80.6 a
Conservation	48.2 b
Cover crop	27.5 c
2021	
Conventional (CONV)	3947 a
Conservation (CONS)	3874 a
Cover crop (COVER)	3775 b
EC_a interactions	
Conventional	103.2 a
Conservation	60.4 b
Cover crop	3.8 ns

[z] values of yield or interactions in a column within the same year and followed by the same letter are not significantly different at the alpha = 5 % level; ns interactions were not significantly different from 0

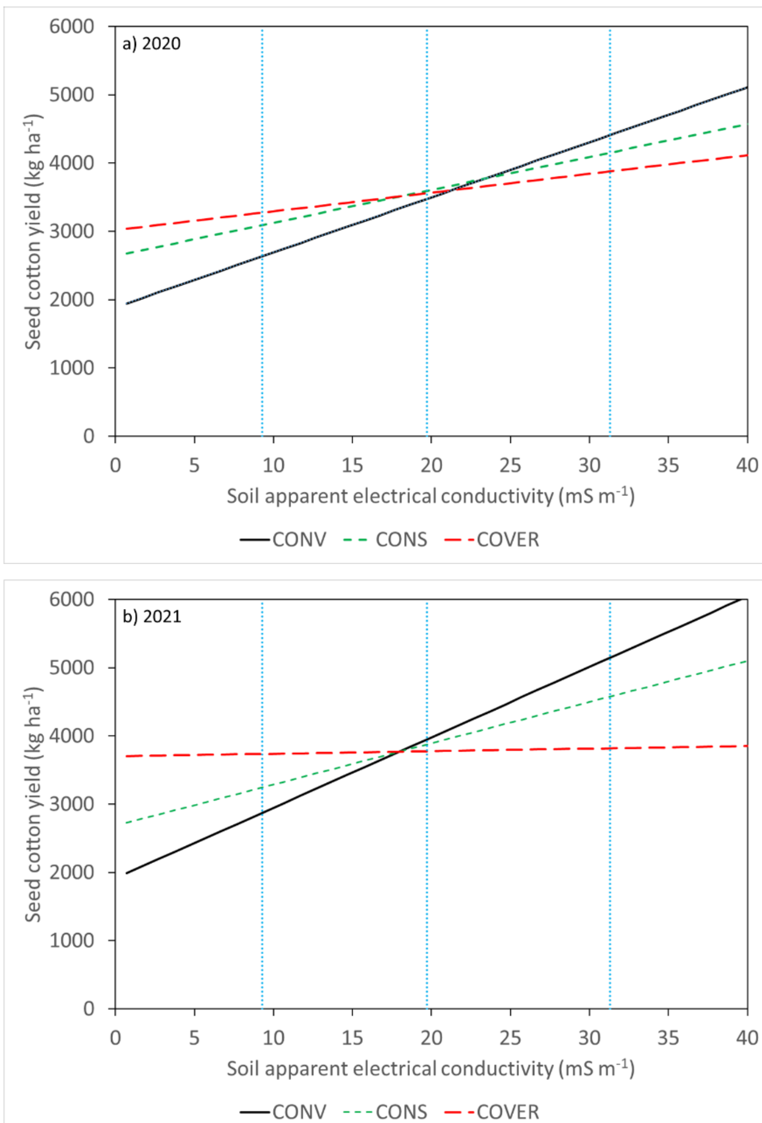

Figure 5. Relationship between seed cotton yield and EC_a for a) 2020 and b) 2021. The vertical lines note the minimum, median, and maximum EC_a values observed in the study area

Two years is a fairly short period to see large improvements from reduced tillage and inclusion of a winter cover crop and this study will continue. Furthermore, it is not wise to make many inferences from two similar growing seasons. While rainfall was less in 2021 (Fig. 3), the study was irrigated, which would minimize any effects of drought stress. The GDD accumulations were similar both years, which suggests that there were no prolonged cool days that sometimes accompany rainfall.

Several interesting observations can be made from these data. Producers often talk about a “yield drag” in the early years after adopting cover crops. While the COVER treatment yields were not significantly lower than the CONV at the median EC_a level in 2020, they were lower in 2021 (Table 3). However, the CONV treatment, which had the most soil disturbance due to the bed preparation just before planting, showed the greatest impact of EC_a variation for both NDVI (Fig. 4) and yield (Fig. 5). The COVER treatment showed the least impact of EC_a variation for both NDVI (Fig. 4) and yield (Fig. 5), with nonsignificant interactions for NDVI (Table 2) and yield (Table 3) in 2021. Analyzing additional dates of crop canopy data may provide further insights into the development of the crop and other indices in addition to NDVI may be useful. Furthermore, numerous additional measurements related to soil health were made in soil samples collected before and during the study and those will continue as well.

Conclusions

This report covers the first two seasons of a study of soil health and cotton production at the Fisher Delta Research, Extension and Education Center in Portageville, MO, USA. While the study is continuing and there were many more measurements than it was possible to include here, some trends were apparent.

- Rainfall was less in 2021 than in 2020; however, the study was irrigated, which would minimize any effects of drought stress.
- The COVER treatment yields were not significantly lower than CONV at the median EC_a level in 2020, but they were lower in 2021, which could suggest the yield drag many producers report when first adopting cover crops.
- The CONV treatment, which had the most soil disturbance due to the bed preparation just before planting, showed the greatest impact of EC_a change for both NDVI and yield.
- The COVER treatment showed the least impact of EC_a change for both NDVI and yield, with nonsignificant interactions for NDVI and yield in 2021.

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