

Effect of Rye and Mix Cover Crops on Soil Water and Cotton Yield in a Humid Environment

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Abstract

In recent years, the use of cover crops is becoming a popular technology among growers in many regions of the United States, which is expected to deliver various benefits such as improving soil health, increasing soil organic matter, controlling weeds, and helping conserve soil water and nutrients. Although expecting these benefits seems reasonable, it is challenging to know how much of these benefits to expect under specific situations. The potential effect of cover crops on soil water conservation is especially significant because of the documented impact of soil water on crop yield, especially for dryland cropping systems. Some researchers have found that planting a cover crop tended to increase soil water, while others have reported the opposite effect. Information on the impact of cover crops on soil water in cotton (*Gossypium hirsutum* L.) production systems in South Carolina is currently lacking. Therefore, the objective of this study was to quantify the effect of cover crops on soil water and cotton yield. A field experiment was conducted in South Carolina during winter, spring, and summer of 2015, with three cover crop treatments. The treatments included: 1) rye (*Secale cereale* L.), planted alone; 2) a mix of six cover crop species; and 3) a control treatment with no-cover. The cover crop was established in the winter, terminated in the spring, and cotton was grown during the summer. Soil water was measured at different depths using capacitance probes and a neutron probe. Our results showed no significant differences in soil water and cotton yield among the cover crop treatments. These results suggest that under the humid conditions of this study, any short-term effect of the cover crop on soil water was masked by timely rain.

Keywords

Soil Moisture, Soil Water, Cover Crop, Cotton, Sensors

1. Introduction

Planting a cover crop rather than leaving the land fallow during the winter is an agronomic practice that has long been promoted since it offers several potential benefits to the soil and the cash crop. Some of these potential benefits include the effect of cover crop on increasing soil organic carbon and carbohydrates [1], supplying soil Nitrogen [2], stabilizing soil temperature [3], suppressing weeds [4] [5], increasing crop yield [6], conserving soil moisture [7], reducing runoff and soil erosion [8], and increasing water use efficiency [9], among other potential benefits. Because of its direct impact on crop yield, one of the most economically significant potential benefits of planting a cover crop is its effect on conserving soil water. However, there is disagreement in the literature about the impact of cover crops on soil water conservation. Some researchers have reported a net gain in soil water due to planting a cover crop, while others have found the opposite.

Examples of researchers who have found that cover crops tended to increase soil water include Karukua *et al.* [10], who compared the effect of cover crop residue in soil moisture in tomato production. They found that the cover crop increased moisture storage, leading to increased tomato yields and water use efficiency. Similarly, Wells *et al.* [5] evaluated the effect of rye cover crop on soil moisture in soybean production. They found that soil moisture was higher in cereal rye mulch treatments compared to a control treatment. Acharya *et al.* [11] reported that cover crops increased soil moisture in the top 30 cm soil depth by 3% to 5% compared to control plots. Stipešević and Kladvko [3], evaluating the effect of winter wheat cover crop in corn production, found that the cover crop increased soil moisture due to its mulching effect. Clark *et al.* [12] also found that soil moisture in the 20 cm soil depth when growing a cover crop was greater than or equal to the no-cover controls throughout the spring and the summer. Daigh *et al.* [13] observed that during the 2012 drought in Iowa and Indiana, planting a rye cover crop either had no impact or significantly increased soil water.

On the other hand, Mitchell *et al.* [7] reported that cover crops tended to decrease soil water. They found that cover crop biomass production may come at the cost of soil water depletion in a semiarid, drought-prone region of California. Similarly, Liebl *et al.* [4], in a four-year study with rye cover crop in Illinois, found that soil water content was the lowest in June under the late-killed rye (killed at planting) during dry periods due to water depletion caused by the growing rye. McGuire *et al.* [14], comparing winter legume cover crop vs. fallow for wheat production, showed that more soil water depletion occurred with the cover crop than in fallow. They also found that heavy rains eliminated any detrimental effect on the following wheat crop during the winter. Kahimba *et al.* [15] found that a cover crop treatment significantly reduced soil moisture during the growing season. Krueger *et al.* [16] found that the soil moisture after rye killed three to four weeks before planting corn was similar to a control treat-

ment, but soil moisture after rye harvested two days before corn planting was 16% lower than the control.

Similarly, Ruiz-Colmenero *et al.* [8] showed that the cover crop treatment reduced soil moisture during a vineyard's vegetative period compared to soils with traditional tillage. They found that although the transpiration through the permanent cover crop was offset by increased infiltration, the cover crop competed actively for water and resulted, on average, in 40% lower grape yields. Meyer *et al.* [17] used long-term simulation modeling to compare cover crops to a bare-soil control. They found that cover crops could significantly reduce soil water content (0 - 120 cm deep) for the following cash crop by a mean of 20 - 50 mm, and up to 80 mm in dry spring conditions. Still, early termination of the cover crop could decrease this negative impact. Thus, they suggested destroying cover crops in late autumn and retaining the residues as mulch to take advantage of the multiple services the cover crops provide during the fallow period while avoiding the negative impact on soil water availability for the following cash crop. In South Carolina, information on the effect of cover crops on soil water in cotton cropping systems is currently lacking. Therefore, the objective of this study was to quantify the impact of winter cover crops on soil water and cotton yield.

2. Methods

2.1. Field Experiment and Data Collection

The field experiment for this study was conducted in 2015 at the Clemson University Edisto Research and Education Center (EREC) near Blackville, SC. The experimental field was 130 m × 110 m and had a Barnwell loamy sand (DaB) soil [18]. The typical soil profile for the Barnwell loamy sand soil has a loamy sand layer in the top 0 - 20 cm depth and a sandy clay loam layer in the 20 - 200 cm depth. The research site was located in the humid southeast USA region with average annual precipitation of 1198 mm, and maximum and minimum air temperatures of 25.6°C and 11.7°C, respectively [19].

The field experiment compared three cover crop treatments using a completely randomized design with four replications. The treatments included: 1) rye planted alone; 2) a mix of six cover crop species; and 3) a control treatment with no-cover. These treatments will be referred to as "Rye," "Mix," and "None," respectively. The Mix treatment included rye (56.7%), oats (14.1%), turnip (3.45%), vetch (7%), radish (3.45%), and crimson clover (14.1%). The cover crop was planted in the winter (1/16/2015) and was terminated in the spring using herbicides and the residue was rolled using a tractor-mounted roller (Landoll Company, Marysville, KS). Cotton was planted on 5/17/2015 in the field during the summer following the cover crop.

Soil volumetric water content (VWC) during the cover crop and cotton growth periods were measured at different depths using capacitance soil moisture sensors and a neutron probe. ECH₂OEC-5 capacitance moisture sensors

(METER Environment, Pullman, WA) were installed at 15, 30, 45, and 60 cm soil depths at the center of each experimental plot. The ECH₂O EC-5 sensors determine VWC by measuring the dielectric constant of the media using capacitance/frequency domain technology. Em50R wireless radio data loggers (METER Environment, Pullman, WA) were used to automatically read the sensors and store the VWC data every hour. Neutron probe tubes were also installed in each plot to measure VWC using the neutron scattering method [20]. The neutron probe VWC was measured weekly using a CPN Hydroprobe™ (CNP, Raleigh, NC) from five soil depths (15, 30, 45, 60, and 76 cm).

Plant samples were collected from each plot on 4/23/15 to determine the dry biomass production from the planted cover crops and the weeds that grew in the control treatment. For the Mix treatment, the plant samples were also divided to determine the biomass production for each of the six cover crop species included in the cover crop mix (rye, oats, turnip, vetch, radish, and crimson clover). Yield from the cotton plots was also measured using a cotton picker equipped with a yield monitor. **Figure 1(a)** shows the established cover crop and control plots, and **Figure 1(b)** shows the same plots just before cover crop termination in the spring. **Figure 1(b)** also illustrates the significant amount of weed pressure in the control plots. **Figure 2(a)** shows one of the soil moisture measurement setups, including the ECH₂O EC-5 sensors connected to an Em50R data logger in one of the plots. **Figure 2(b)** shows the cotton planted after the cover crop was

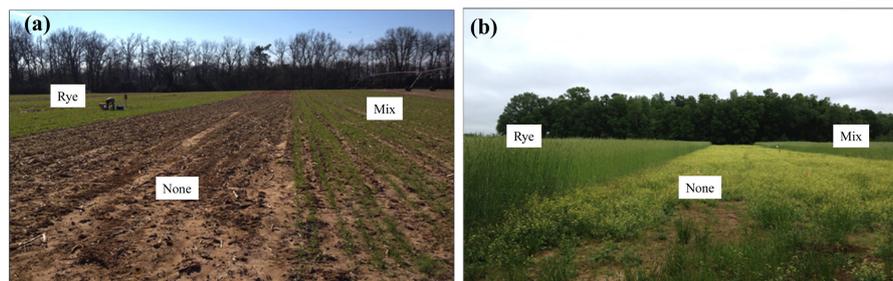


Figure 1. (a) Established cover crop and control plots, and (b) Cover crop fully-grown and weeds growing in the control plot.

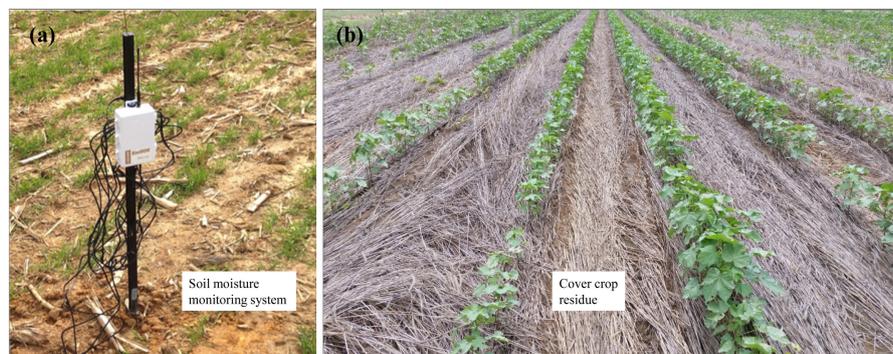


Figure 2. (a) Field setup to measure soil moisture in one of the experimental plots, and (b) Cotton planted after cover crop, showing cover crop residues between the cotton rows.

terminated, showing the plant residue mulch remaining from the cover crop. Daily weather data for 2015 was obtained from an electronic weather station operated by NOAA, which is located within the EREC research farm.

2.2. Statistical Analyses

2.2.1. Analysis of ECH₂O EC-5 Sensors VWC Data

The statistical analysis of the VWC data from the ECH₂O EC-5 sensors focused on the average soil moisture (ASM), which was calculated as the arithmetic average of the four depths' daily VWC. Two types of analyses were conducted for ASM from the ECH₂O EC-5 sensors, focusing on mean daily soil moisture loss (EC5_ASMLoss), which was the difference between the current ASM and the ASM measured the day before. In the first analysis, the mean daily moisture loss was modeled, stratifying by season (cover crop season vs. cotton season) and controlling for new daily infiltration. In the second analysis, the daily moisture loss was modeled, stratifying by month and controlling for new daily infiltration. Data from January and May were excluded from analysis since these months represented transitional periods in crop establishment and soil moisture data collection. Both types of analyses employed a repeated-measures conditional-means model (controlling for daily new infiltration) where the mean square for error was taken from the observed between-plot variation. All analyses were conducted in R 3.6.2 [21] on a Windows 10 platform (the code for conducting analyses is available upon request). In both sets of analyses, the fitted models were of the form,

$$EC5_ASMLoss_{ijk} = \mu + Treat_i + Infiltration_{ijk} \times \beta + Day_{ijk} + Plot_k \quad (1)$$

where, $Day_{ijk} \sim N(0, \sigma_d^2)$, $Plot_k \sim N(0, \sigma_e^2)$, and μ correspond to the average soil moisture loss across all days and plots, and β is a correction factor to accommodate the effect of new daily infiltration on moisture loss. The quantities $Treat_i$, $Infiltration_{ijk}$, Day_{ijk} , and $Plot_k$, represent the treatment effect, observed daily infiltration, treatment/day/plot specific effect, and plot-specific variation, respectively. In each analysis, the data were subset according to records belonging to the desired growing season or months, and individual models were fitted to the data belonging to each stratum.

2.2.2. Analysis of Neutron Probe VWC Data

The neutron probe daily soil moisture loss (NP_ASMLoss) data were analyzed using the average soil volumetric water content (VWC) calculated as the arithmetic average of four depths. Because of the frequency of data collection with the neutron probe, we could not conduct the analysis on the average daily moisture loss. Instead, the data analysis focused on mean VWC stratifying by month and growing season (cover crop season or cotton season). In both analyses, the data were stratified according to whichever month/season was of interest, and the following model was fitted:

$$NP_ASMLoss_{ijk} = \mu + Treat_i + Day_{ijk} + Plot_k \quad (2)$$

where, $Day_{ijk} \sim N(0, \sigma_d^2)$, $Plot_k \sim N(0, \sigma_e^2)$. All error calculations were made using the between-plot variation *i.e.* σ_e^2 .

2.2.3. Analysis of Cotton Yield and Cover Crop Biomass Data

The analyses of the cotton yield and cover crop biomass were conducted using the following models:

$$CottonYield = \mu + Treat_i + Plot_k \quad (3)$$

$$CoverCropBiomass = \mu + Treat_i + Plot_k \quad (4)$$

where, $Treat_i$ represents the cover crop treatment effect, and $Plot_k \sim N(0, \sigma_e^2)$, the plot-specific variation. A Tukey's comparison was conducted to compare means amongst the three treatments.

3. Results and Discussion

3.1. ECH₂O EC-5 Sensors Data

The hourly VWC data are presented in **Figure 3**. They were collected from four soil depths using the ECH₂O EC-5 sensors installed in one of the control plots (plot CC105). **Figure 4** illustrates the data included for ASM analyses. The top, middle, and bottom panels correspond to the daily ASM values for the plots in the Mixed, None (no cover), and Rye treatments, respectively.

The results of the by-season and by-month analyses of ASM are presented in **Figure 5** and **Table 1**. Due to the scale of the day-over-day differences in ASM, all values were presented as percentages rather than on the original ratio scale. Results of the by-Season Analysis, including the fitted means and associated confidence intervals, are shown in the top panel of **Figure 5** and the first block of rows in **Table 1**. We observed that treatment did not significantly impact the mean moisture loss after controlling for daily infiltration. The furthest left point at the top-left panel of **Figure 5** indicates that the mean percent ASM loss for the mixed cover crop plots during the cover crop season was -0.25 with a 95% confidence interval of -0.28 to -0.22 . These results mean that we expected the

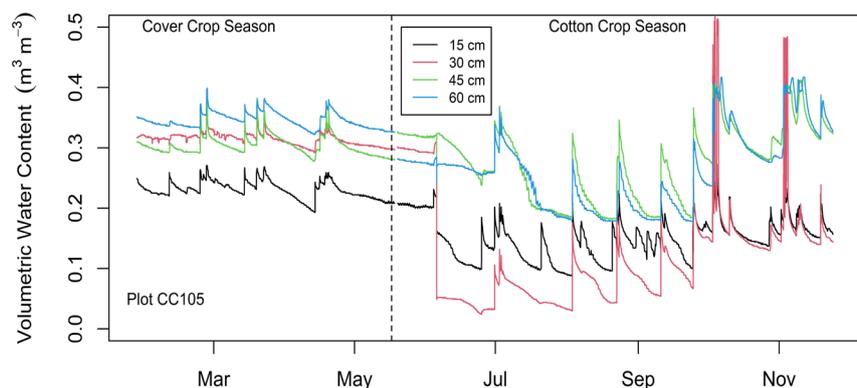


Figure 3. Volumetric water content (VWC) measured with ECH₂O EC-5 sensors at four depths on a cotton plot (plots # CC105) during the cover crop and cotton growing season in 2015. The plot did not have a cover crop during the off-season. The vertical line represents the cotton planting date.

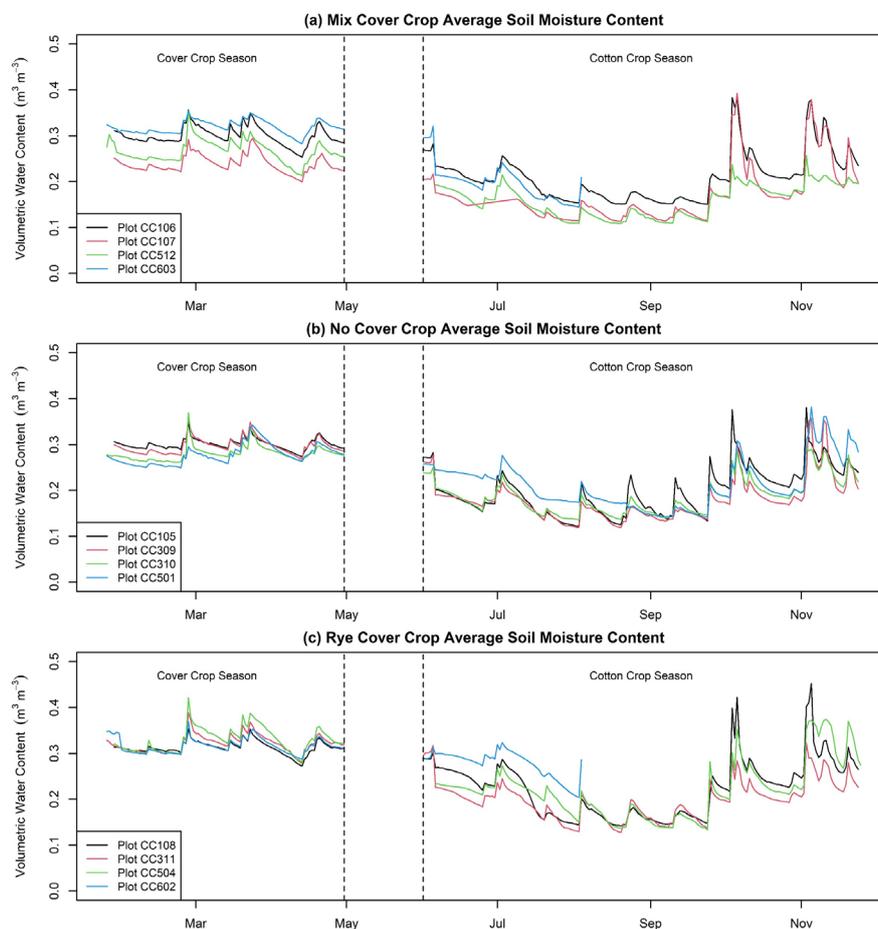


Figure 4. Average soil moisture (ASM) measured as the arithmetic average of measured soil moisture at four depths. The top panel corresponds to the daily ASM measurements for each of the plots in the Mix cover crop treatment. The middle panel presents the same for the control (no cover crop) treatment. The lower panel illustrates the daily ASM for the plots in the rye cover crop treatment.

percent ASM loss to decrease daily for Mix cover crops by -0.25 with the corresponding confidence interval.

Similarly, the furthest right point (in the top panel) indicates that the mean ASM loss for the rye cover crop during the cotton season was -0.52 with a 95% confidence interval of -0.66 to -0.39 . It is worth noting that none of the treatments differed significantly within seasons with respect to the mean percent ASM loss. While the confidence interval for the Mix crop did not overlap with the confidence intervals for the rye and None treatments during the cover crop season, the discrepancy between the mean percent ASM loss can hardly be considered significant from a practical standpoint.

For the by-month analyses, we observed similar results that are summarized graphically in the bottom panel of **Figure 5** and the lower block of rows in **Table 1**. The bottom panel of **Figure 5** shows that the furthest-right point corresponds to the mean percent ASM loss for the rye cover crop group during August with a value of -1.23 and a corresponding 95% confidence interval (CI) of -1.58 to

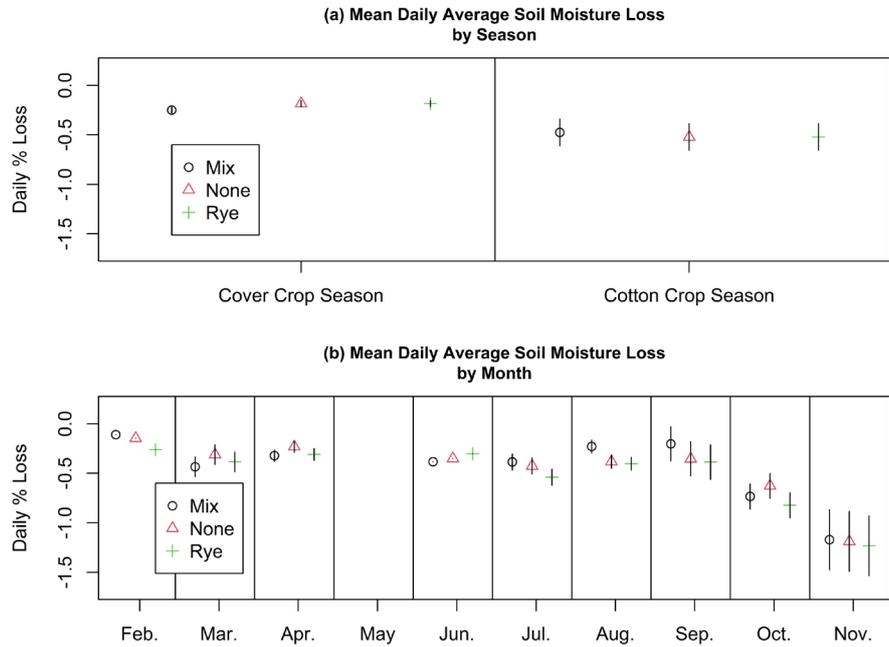


Figure 5. Means plots by cover crop treatment, stratifying by cover crop season (Cover vs. Cotton), and by month. The location of the symbols indicates the point estimate for the mean % ASM loss, and the vertical segments demonstrate a 95% confidence interval for the estimate. Note that within February and June, there was not enough between-plot variation for these months to accurately estimate the error, as such confidence intervals are not reported for these months.

Table 1. Estimated mean percent ASM loss. Results are presented for each cover crop type and stratified by cover crop season (Cover Crop vs. Cotton) and month (excluding January and March).

Mean Percent Average Soil Moisture Loss			
By Season			
Season	Mix	None	Rye
Cover Crop	-0.25 (-0.28, -0.22)	-0.18 (-0.21, -0.15)	-0.18 (-0.21, -0.15)
Cotton	-0.48 (-0.61, -0.34)	-0.52 (-0.66, -0.39)	-0.52 (-0.66, -0.39)
By Month			
Month	Mix	None	Rye
Feb.	-0.11 (*)	-0.15 (*)	-0.26 (*)
Mar.	-0.43 (-0.55, -0.32)	-0.31 (-0.43, -0.20)	-0.38 (-0.5, -0.27)
Apr.	-0.32 (-0.39, -0.26)	-0.23 (-0.30, -0.17)	-0.31 (-0.38, -0.24)
Jun.	-0.38 (*)	-0.35 (*)	-0.30 (*)
Jul.	-0.39 (-0.48, -0.29)	-0.43 (-0.52, -0.33)	-0.54 (-0.63, -0.45)
Aug.	-0.23 (-0.31, -0.15)	-0.38 (-0.46, -0.31)	-0.40 (-0.48, -0.33)
Sep.	-0.20 (-0.40, 0.00)	-0.35 (-0.55, -0.15)	-0.39 (-0.59, -0.19)
Oct.	-0.73 (-0.88, -0.59)	-0.63 (-0.78, -0.48)	-0.82 (-0.97, -0.68)
Nov.	-1.17 (-1.52, -0.82)	-1.19 (-1.54, -0.84)	-1.23 (-1.58, -0.88)

–0.88. It is worth noting that, like in the by-season analyses, the Mix cover crop had marginally non-overlapping interval with the other two cover crop types (–0.31 to –0.15 vs. –0.46, –0.31 and –0.48, –0.33 for None and rye cover crop, respectively). However, this was only observed during August and, as such, should not be over-interpreted. In all, we observed no consistent differences in moisture retention when stratifying by-season or by-month.

3.2. Neutron Probe Data

The results from the neutron probe ASM data analyses, both by-season and by-month, are shown in **Table 2** and **Figure 6**. The by-month results in **Table 1** show that in February, the mean soil moisture for the Mix cover crop plots was 0.28 with a corresponding confidence interval (0.26, 0.31). The related point in **Figure 6** can be found in the bottom panel (black circle and associated line segment illustrating the 95% CI) furthest point to the left. It shows that the rye cover crop had almost consistently (excepting September) the highest average soil moisture. However, when considered in contrast to the expected margins of error, the observed soil moistures offer only marginal evidence that the rye cover crop may increase average soil moisture.

3.3. Cover Crop Biomass and Cotton Yield Production

3.3.1. Cover Crop Biomass Production

The average biomass production for the Mix, Rye, and None treatments was 4138, 4941, and 1791 kg/ha, respectively. **Figure 7(a)** showed no significant difference in biomass production between the Mix and Rye cover crop treatments,

Table 2. Mean average soil moisture (95% CI) as measured by neutron probe. Means are presented stratifying by month and cover crop season (note that May was excluded due to cotton crop planting, and there were no neutron probe measurements in June). * denotes that there was not enough between plot variation to estimate the error accurately.

Mean Average Soil Moisture by Neutron Probe			
By Season			
Season	Mix	None	Rye
Cover Crop	0.28 (0.26, 0.31)	0.30 (0.27, 0.32)	0.32 (0.30, 0.34)
Cotton	0.21 (0.20, 0.23)	0.23 (0.21, 0.24)	0.24 (0.22, 0.26)
By Month			
Month	Mix	None	Rye
Feb.	0.28 (0.26, 0.31)	0.29 (0.27, 0.32)	0.32 (0.29, 0.34)
Mar.	0.29 (0.27, 0.31)	0.31 (0.28, 0.33)	0.33 (0.31, 0.35)
Apr.	0.28 (0.26, 0.30)	0.29 (0.27, 0.31)	0.31 (0.29, 0.34)
Jul.	0.21 (0.19, 0.23)	0.22 (0.20, 0.23)	0.25 (0.23, 0.27)
Aug.	0.21 (0.19, 0.22)	0.23 (0.21, 0.24)	0.23 (0.21, 0.24)
Sep.	0.19 (*)	0.21 (*)	0.20 (*)

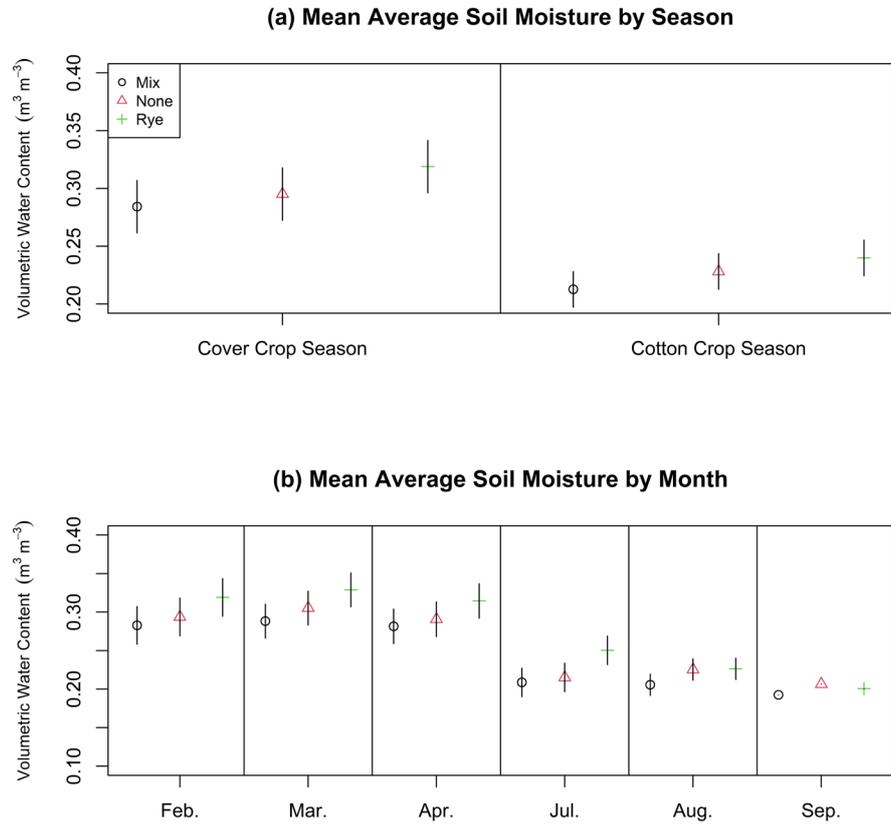


Figure 6. Mean average soil moisture with corresponding 95% confidence intervals as measured by neutron probe. Means are presented stratifying by month and cover crop season (note that May was excluded due to cotton crop planting, and there were no neutron probe measurements in June).

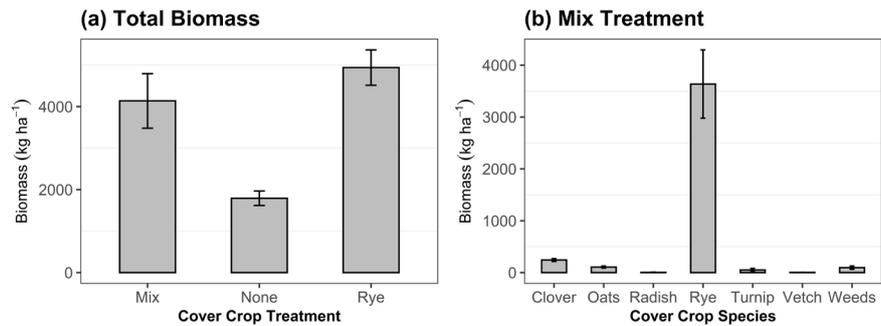


Figure 7. (a) Total biomass produced by cover crop treatment measured on 4/23/15, and (b) Biomass produced by each cover crop species in the Mix treatment.

but the control treatment produced significantly less biomass than the other two treatments. Still, the control treatment without cover crop (None) produced a considerable amount of biomass from weeds. The production of weeds is a problem for farmers since they must be controlled before crop planting. The amount of biomass produced by the Mix and Rye cover crops provides mulch for the cash crop. The mulch could have potential benefits to the soils and cash crop, such as increasing soil organic carbon and carbohydrates, supplying soil

Nitrogen, stabilizing soil temperature, suppressing weeds, reducing runoff and soil erosion, among other benefits [2] [3] [4] [5] [8] [11]. **Figure 7(b)** shows the different species' biomass in the Mix treatment, which indicates that the rye species predominated. There were insignificant amounts of biomass produced by all the other species. These results suggest that the percentage of rye seeds in the seed mixture should be reduced considerably to allow the other cover crop species in the mixture to grow.

3.3.2. Cotton Yield Production

The mean yield was 1259 kg/ha (95% CI 836, 1682) for the Mix cover crop treatment, 1066 kg/ha (95% CI 700, 1433) for the no cover crop (None) treatment, and 1132 kg/ha (95% CI 766, 1499) for the Rye cover crop treatment. The cotton yield analysis showed no significant differences between the mean yields among the three cover crop treatments (**Figure 8**).

3.4. Impact of Rainfall on Cover Crop Treatment Effect

The daily and cumulative rain during 2015 at the study site are shown in **Figure 9**, and the monthly rainfall totals are shown in **Table 3**. **Figure 9** showed frequent rain during 2015, totaling 1315 mm, which was greater than the long-term average for the site (1198 mm per year). Rainfall during the cover crop growing period (January to April) averaged 112 mm/month. Also, there was significant rain (118 mm) in April, which replenished the soil profile just before the cover crop was terminated. Therefore, the soil profile was relatively saturated during the cover crop period, negating the cover crop potential effect on soil water. Although there was little rain in May (10 mm), there was significant rain in early June (95 mm), after the cotton crop was planted, which refilled the soil profile and counteracted any potential carry-over effect of the cover crop on soil water.

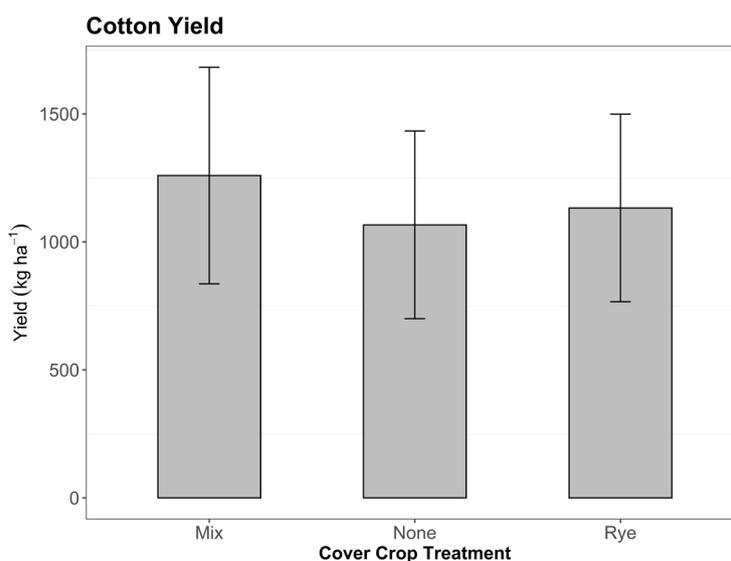


Figure 8. Cotton mean yield and corresponding 95% confidence intervals by cover crop treatment.

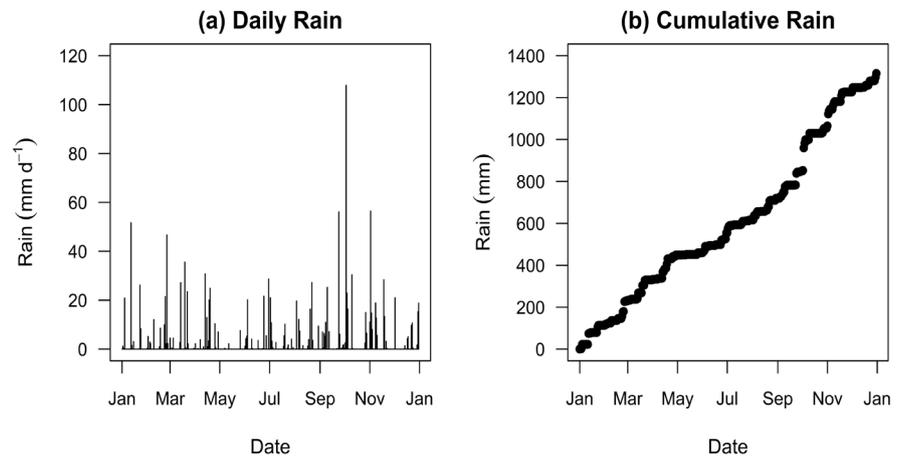


Figure 9. Daily and cumulative rainfall during 2015 in Blackville, SC.

Table 3. Monthly rain (mm) during 2015 in Blackville, SC.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
113	115	102	118	10	95	62	103	129	205	173	89	1315

Several rain events in early July also contributed to replenish the soil profile during the early portion of the cotton-growing season. The impact of these rainfall events on soil VWC can be observed in [Figure 4](#). These timely rainfall events offer some explanation as to why there was no significant effect of the cover crop treatments on soil water, neither during the cover crop season nor during the cotton season. It also demonstrates why there was no treatment effect on cotton yield.

4. Conclusion

In this experiment, Rye, Mix, and control (None) cover crop treatments were compared to evaluate their effects on soil water during both the cover crop growing season and the cotton-growing season. We also assessed the impact of the cover crop treatments on cover crop biomass production and cotton yield. Time series data of VWC were collected hourly using automatic capacitance soil moisture probes installed at four soil depths. Also, less frequent measurements were taken using a neutron probe. Our results showed that under the conditions of this study, the cover crop treatments had no significant effect on soil water. Also, the cover crop treatments did not affect cotton yield. However, the two cover crop treatments (Mix and Rye) provided a significant amount of biomass compared to the control, potentially offering additional benefits to the soil and the cash crop. The timely and abundant rain observed in this study masked any potential effect of the cover crop on soil water during the study. In this study, the cover crop had no detrimental impact on reducing soil water for the cash crop; however, there are many other beneficial aspects that the cover crop provides for the cash crop including weed suppression and nutrient recycling.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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