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Long-term Changes in Soil Surface Properties as affected by Management Practices in a Wheat-soybean, Double-crop System

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Abstract

Long-term agricultural sustainability and productivity are controlled by the integrative effects of different management practices on the soil. Many Arkansas producers use the double-crop system to grow soybeans [*Glycine max* (L.) Merr] and wheat (*Triticum aestivum* L.). Studying combinations of different, non-traditional, alternative agricultural techniques may help producers better understand the long-term implications of various management practice options on sustainability and productivity. The objective of this study was to evaluate the effects of agricultural management practices, including residue level, tillage, irrigation, and burning, and soil depth on the change in various soil properties from 2010 to 2020 in a long-term, wheat-soybean, double-crop system on a silt-loam soil (Glossaquic Fraglossudalfs) in eastern Arkansas. Soil nutrients tended to accumulate over time, the most in the top 10 cm, while soil nutrient contents in the 10- to 20-cm depth interval tended to not significantly change over time. Soil bulk density generally decreased across all treatments over time, particularly under no-tillage (NT)/non-burning (NB) management in the top 10 cm of the soil. Soil organic matter (SOM) content increased under all treatment combinations by 0.097 kg ha^{-1} yr^{-1} but numerically increased the most in the NT/NB treatment at the top 10 cm of the soil. Total carbon (TC) was 9.2 times greater, total nitrogen (TN) was 48 times greater, TC:SOM was three times greater, and TN:SOM was 3.7 times greater in the top 10 cm of the soil. Soil electrical conductivity was 1.5 times greater under conventional tillage and averaged across other treatment combinations. Soil pH was 1.9 times greater under irrigation than under non-irrigated treatments. Quantifying soil-property change over time will help producers to better understand the long-term effects of various residue and water management practices and to find reasonable, more sustainable alternative practices.

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Introduction and Literature Review

The wheat (*Triticum aestivum* L.)-soybean [*Glycine max* (L.) Merr] double-crop has been common in the mid-South since after World War II and was adopted by many southern states, including Arkansas (Marra & Carlson, 1986). In 2020, approximately 1.14 million hectares of soybeans and 58,679 hectares of wheat were planted in Arkansas (NASS, 2021). Today, producers are focused on sustainability and conservation of water and soil resources.

The double-crop system is more financially productive and more sustainable than many alternative methods. Double-cropping leads to increased productivity from year-round cropping and reduced soil erosion and water loss from longer soil coverage (Sanford, 1982). However, using different combinations of management techniques, such as burning and non-burning, conventional tillage (CT) and no tillage (NT), high and low residue levels (fertilizer levels), and different irrigation methods, may have beneficial effects on the soil over time.

While using a double-crop system, many producers find it valuable to burn the wheat residue in between crops. Burning the residue provides the short-term benefits of weed control and preparing the seed bed for planting (Chan & Heenan, 2005). Despite the short-term advantages of residue burning, a study conducted in western Canada revealed there were no long-term benefits to burning the wheat residue (Biederbeck et al., 1980). The three experimental sites studied were continuous wheat crop systems where burning was conducted each spring from 1956 to 1977. Surface soil textures at these sites included silty clay, clay, and loam. Immediately after burning, the soil showed greater levels of P and N, and these nutrient increases produced crop yields 100 kg/ha greater than in plots with no burning in the early season. However, the added P and N were rapidly leached deeper into the soil profile or taken up by plants. Ultimately, the no-burn sites had 0.5% more total C in the first 2.5 cm of the soil and

0.3% more total C in the top 15 cm of the soil. Similarly, the total N was 0.02% greater in the no burn site compared to the burned site. Residue burning also resulted in greater than 50% less bacterial and fungal activity at the 0-2.5 cm depth compared to sites where no burning occurred. Biederbeck et al. (1980) concluded that non-burning resulted in levels of soil organic matter, microbes, and other beneficial nutrients that were significantly higher than under residue burning.

Conventional tillage and NT are two ways of preparing soil and managing surface residues for crop production. Conventional tillage involves plowing or other intensive tillage and leaves less than 15% residue coverage after planting. No tillage is a type of conservation tillage, where the soil is left undisturbed after a harvest. Planting via NT is achieved by a narrow seedbed or slot. Conservation tillage leaves over 30% residue coverage at the time of seeding, while NT can leave up to nearly 100% surface coverage with residue (Padgitt et al., 2000). When NT methods are used in double-crop systems, the producer saves time and money in the form of labor and machinery costs (Marra & Carlson, 1986). Another advantage of the NT method is the general increase in soil organic matter (SOM) and nutrients over time, at least in the upper several centimeters of the soil (Sanford, 1982).

Many studies have been conducted comparing CT and NT methods. In 1995, Six et al. (1999) conducted an experiment at four sites in NE, OH, MI, and KY with soil surface textures of loam, silt loam, sandy loam, and silty clay loam, respectively. The study revealed that CT resulted in total C levels 9 to 16% lower than NT sites, suggesting that NT results in greater soil C sequestration. No-till also leads to reduced soil disturbance and increased soil aggregation (Six et al., 1999). Another study was conducted on a Georgia coastal sandy clay loam during 1984 and 1985 (NeSmith et al., 1987). This study reported that from a 25 to 30 cm depth, volumetric water content was 0.06 to 0.08 m^3/m^3 greater in sites that used NT compared to CT sites (NeSmith et al., 1987). The CT management method resulted in soil compaction in the 15 to 25 cm depth. Beginning the NT method on already compacted soil does not alleviate previous compaction, so a suggested fix would be to first loosen the compacted zones (NeSmith et al., 1987). In Mississippi, Sanford (1982) conducted an experiment over 4 years on a wheat-soybean double-crop system planted in silty clay. He discovered that, over time, SOM levels were 0.31 to 0.18% greater in plots under NT and no residue burning compared to plots under either CT or burning. Sanford (1982) also analyzed crop profits and showed that treatments with residue burning and NT produced the greatest profits. However, as previously mentioned, residue burning may have long-term negative effects on SOM and other nutrients such as C, P, and N. Each study concluded that the NT method was more cost effective and better for soil health over time than CT methods. In addition to tillage practices, irrigation practices also play a role in soil health over time.

Irrigation management practices can affect the sustainability and profitability of crop systems. In Arkansas, between 1972 and 2003, the mean annual irrigated crop yield for soybean was 2515 kg ha^{-1} compared to a non-irrigated yield of 1482 kg ha^{-1} (Egli, 2008). Although greater crop yields can lead to greater profit, in some cases the up-keep for an irrigation system can be more costly than the profits made from the crop. Parsch et al. (2001) reported that non-irrigated soybean under CT was the most profitable of the tested methods, having a net return greater than other tested systems by \$30 ha^{-1}. However, since non-irrigated systems rely on rainfall only, producers may be risking all profits by not irrigating their crop. Because of this, guaranteed profits are harder to predict due to seasons with less rainfall or drought (Parsch et al., 2001).

Irrigation practices may also have long-term negative effects. Beginning in 1985, a 3-year study was conducted by Daniels and Scott (1991) in a wheat-soybean, double-crop system in Fayetteville, AR with a surface soil texture of silt loam. The study reported that the non-irrigated, wheat-soybean, double-crop system had a water-use efficiency (WUE) of 66.8 kg ha^{-1} cm^{-1}, which was 2.7 kg ha^{-1} cm^{-1} greater than the irrigated system. The non-irrigated system also had lower evapotranspiration (25.5 cm) compared to the irrigated system (37.5 cm). The greater WUE and lower evapotranspiration suggest that, while irrigated systems produce greater crop yields, irrigated crops may be less sustainable than non-irrigated crops in terms of water use (Daniels & Scott, 1991). Another detrimental consequence of irrigation is that irrigation draws water from aquifers. According to Scott et al. (1998), the Alluvial Aquifer in Arkansas may be depleted as soon as 2050 due to water withdrawal rates for crop irrigation exceeding recharge rates.

Similar to irrigation options, the application of different levels of N fertilizer to the soil can result in varying levels of wheat residue. High and low residue levels can affect many soil properties, such as SOM, total C, N, P, and soil aggregation (Norman et al., 2016). Soil aggregates are stable if they can withstand forces such as wind and water erosion and tillage. Soils that have stable aggregates are less prone to erosion and can maintain greater levels of SOM and total C, by physical protection, due to the decreased erosion (Smith et al., 2014). Using methods such as CT to cultivate land can break down soil aggregates and lead to lower levels of SOM, total C, N, and P over time (Cambardella & Elliot, 1993). Studying high and low residue levels can help predict what long-term effects the varying levels of residue will have on soil properties.

Since 2002, high and low residue level treatments have been applied to a silt-loam experiment site in eastern Arkansas. According to Smith et al. (2014), wheat residue levels were 80.4% greater under the high than the low fertilizer application. Brye et al. (2007) reported that SOM was greater in the no-burn/low-residue-level treatment combination compared to the other bun-residue-level combinations. Brye et al. (2007) also reported the soil C:N ratio was greater in the no-burn/high-residue-level treatment combination compared to the other bun-residue-level combinations. Additionally, Amuri et al. (2008) reported that SOM increased evenly across all treatments by 0.097 kg m^{-2} yr^{-1} and was unaffected by a specific treatment or combination of treatments, including CT/NT, residue burning/non-burning, and high/low residue level, in the first six years of altered management. The study also reported that, in the top 10 cm, total soil C increased by 0.073 kg C m^{-2} yr^{-1} under the high- compared to the low-residue treatment (0.054 kg C m^{-2} yr^{-1}) (Amuri et al., 2008). Despite the increase in total soil C, the reported amount of extractable P in the top 10 cm of the soil decreased over time in the first six years after altered management practices. However, the decrease can be explained by plant uptake of available nutrients and removal from harvested plant materials (Amuri et al., 2008).

More recent studies conducted at the same eastern Arkansas site focused more on long-term residue-level effects on soil aggregation. Smith et al. (2014) reported that, within the high-residue-level treatment, total water soil aggregate (TWSA) concentrations decreased by 13% in the top 15 cm of soil. Total WSA C concentrations were unaffected by residue level, but TWSA N concentration increased 8% under the high- compared to the low-residue-level treatment. Smith et al. also reported that the C:N ratio was 6.2% greater under the irrigated, high-residue-level than the irrigated, low-residue-level treatment combination. Similar to Smith et al. (2014), Desrochers et al. (2019) reported microaggregate concentrations 1.1 times greater in the high-than in the low-residue-level treatment. Across burned treatments, particulate organic matter (POM) C and N levels were 1.9 times greater in the low- than in the high-residue-level treatment. Across irrigated treatments, coarse POM-N concentrations were 21.0% greater in high- than in the low-level residue treatments (Desrochers et al., 2019). Despite these findings, more field research is needed to establish a concrete relationship between soil aggregation, residue level, and soil nutrient concentrations.

Justification

Long-term sustainability has become a major concern for crop producers. With the wheat-soybean, double-crop production system being relatively widespread throughout the southeastern U.S., it is important to monitor and study the various methods and treatments that producers may employ to grow their crop. Using the CT method can result in lower levels of total C in the soil; using irrigation can be more costly and less water efficient; burning residue can cause a decrease in SOM and microbial activity. These are only a few of the consequences to using various, traditional management practices for soybean production. Studying the effects of high- and low-residue levels, CT and NT, burning and non-burning, and irrigation and non-irrigation can help producers better understand not only the short-term effects these treatments have on soybean production, but also the long-term effects on soil physical and chemical properties and sustainability as well.

Objective and Hypotheses

The objective of this study was to evaluate the effects of agricultural management practices, including tillage, residue level/fertility, residue burning, and irrigation scheme, and soil depth on the change in various soil properties over time (i.e., from 2010 to 2020) in a long-term, wheat-soybean, double-crop production system on a silt-loam soil in eastern Arkansas. It was hypothesized that BD, SOM, and TC would increase over times under NT and no burning and the increase over time would be greater in the 0-10 cm depth than under CT, burning, and in the 10-20 cm depth. It was also hypothesized that BD, pH, and EC would change across time over the different irrigation and burning treatments and that SOM, TC, and TN would increase over time more in the high- than in the low-residue-level treatment.

Materials and Methods

Site Description

A long-term field study was initiated at the Lon Mann Cotton Branch Experiment Station near Marianna, Arkansas in 2001 (Cordell et al., 2006). The soil at the field site is a Calloway silt loam (fine silty, mixed, active, thermic Glossaquic Fraglossudalfs) (Web Soil Survey, 2020).

The 30-year mean annual air temperature and precipitation for the study area are 16.6°C and 128 cm, respectively (NOAA, 2020). The mean monthly maximum and minimum air temperatures are 32.9°C in July and -0.6°C in January (NOAA, 2020).

Field Management

Prior to the establishment of this long-term field study in 2001, the experimental site was used for soybean monocropping under CT. In fall 2001, in order to prepare the site for the wheat-soybean, double-crop field study, the site was disked two times and fertilized with a broadcast application of N, P, and K, along with pelletized limestone to adjust pH (Cordell et al., 2006). In early to mid-November each year, wheat was drill-seeded at a rate of 90 kg seed ha^{-1} with 19-cm row spacing. In late March from 2002 to 2004, all 3- by 6-m plots were fertilized by hand using urea (46% N) at a rate of 101 kg N ha^{-1}. In 2005, a wheat crop was not established due to wet soil conditions, and therefore no fertilizer was applied. Since 2006, the high-residue-level plots received a split application of 101 N kg ha^{-1} in late February to early March, while low-residue-level plots received no N fertilizer.

A plot combine was used for the wheat harvest every year in late May to early June. After harvesting wheat, a tractor-powered rotary mower was used to mow the remaining wheat stubble to a height of ≤ 10 cm. On plots that received the burn treatment, burning was achieved by propane flaming. Next, plots that received the CT treatment were disked two or three times to a depth of 7 to 10 cm, followed by a soil conditioner to smooth the seedbed. The study site consisted of 48 plots, with three replications of irrigation-tillage-residue burning-fertility/residue level treatment combinations.

A glyphosate-resistant soybean (maturity group 5.3 or 5.4) was drill-seeded at a rate of 47 kg seed ha^{-1} with 19-cm row spacing in mid-June from 2002 to 2013. From 2014 on, an enhanced glyphosate-resistant soybean (maturity group 4.9) was drill-seeded at a rate of 101 kg seed ha^{-1}. Potassium fertilizer was applied at Arkansas Cooperative Extension Service (UACES, 2000) recommended rates in years when needed. After soybean planting in 2005, a levee was added to prevent water intrusion into the non-irrigated plots. Furrow-irrigation was used on the irrigated plots as needed. A plot combine was again used in late October to early November each year to harvest the soybean crop, and the remaining soybean stubble was left untouched before planting the next wheat crop in early to mid-November.

Soil Sample Collection, Processing, and Analyses

Composite soil samples were manually collected at the end of the wheat growing season (late May to early June) in 2010 and 2020 with a 4.8-cm-inside-diameter core chamber and slide hammer from the 0- to 10- and 10- to 20-cm depths in each plot. Cores were collected after wheat harvest, but before tillage and soybean planting. After oven drying at 70^{o}C for 48 hours, soil samples were weighed for bulk density determination, and then were ground and sieved through a 2-mm mesh screen for chemical analysis. Soil pH and electrical conductivity (EC) were determined using an electrode in a 1:2 (wt/vol) soil:water suspension. After 2 hours at 360^{o}C, soil organic matter (SOM) concentration was determined by weight-loss-on-ignition. Total soil C (TC) and N (TN) concentrations were determined by high-temperature combustion (LECO CN-2000 analyzer, LECO Corp., St. Joseph, MI in 2010 and Elementar VarioMAX CN analyzer, Elementar Americas Inc., Ronkonkoma, NY in 2020). Using the measured bulk density and 10-cm depth interval, SOM, TC, and TN measured concentrations were converted to contents and reported in units of Mg ha^{-1}. The soil C:N ratio was calculated using the measured C and N concentrations. Similarly, the TC:SOM and TN:SOM ratios were calculated using the measured TC, TN, and SOM concentrations.

To determine change over time, the 2010 data were subtracted from the 2020 data, on a plot-by-plot basis, and divided by the fractional change in time. The change-over-time data were used for statistical analyses.

Statistical Analyses

A four-factor analysis of variance (ANOVA) was conducted using SAS (version 9.4, SAS Institute, Inc., Cary, NC) to evaluate the effects of tillage, residue burning, fertility/residue level, soil depth, and their interactions on the change in soil properties (i.e., BD, pH, EC, SOM, TC, TN, C:N, TC:SOM, and TN:SOM) over time from 2010 to 2020. Due to a confounding experiment design with the residue burning and irrigation treatments, a separate four-factor ANOVA was conducted to evaluate the effects of tillage, irrigation, fertility/residue level, soil depth, and their interactions on the change in soil properties (i.e., BD, pH, EC, SOM, TC, TN, C:N, TC:SOM, and TN:SOM) over time from 2010 to 2020. When appropriate, means were separated by least significant difference at the 0.05. Significance was judged at $P < 0.05$.

Results and Discussion

Field Treatment Effects Ignoring Irrigation

With the exception of soil pH and C:N ratio, the change in all other measured or calculated soil properties over time were affected by at least one of the field treatments tested (i.e., tillage, fertility/residue level, and/or residue burning) when the irrigation factor was ignored (Table 1). Averaged across tillage, fertility/residue level, and soil depth, the change in TN content over time was more than two times greater ($P = 0.02$; Table 1) under no burn (0.200 Mg ha^{-1} yr^{-1}) than under burn (0.096 Mg ha^{-1} yr^{-1}). However, soil TN content did not change over time from 2010 to 2020 in either burn treatment. The greater levels of TN under NB than B were likely at least partially due to the cumulative effects of crop residue retention on the soil surface when not burned that slowly contributed N to the soil as the residues decomposed and mineralization occurred, which were processes that could not have occurred to a similar magnitude when most of the surface residue was lost when burning occurred (Brye, 2012). Furthermore, without burning, organic N in the crop residue remains on the soil surface in a non-leachable form until oxidation and mineralization occur. However, similar to the results of Biederbeck et al. (1980), once burned, any remaining charred residue is more easily and quickly decomposed, releasing N that may easily leach and/or be taken up by plants, both of which could lower soil N concentrations in the top 20 cm of the soil.

Averaged across tillage, fertility/residue level, and burn treatments, the change in soil TN content over time was also 46 times greater (*P* < 0.01; Table 1) in the top 10 cm (0.290 Mg ha^{-1} yr^{-1}) than in the 10-20 cm soil depth interval (0.006 Mg ha^{-1} yr^{-1}). Soil TN in the 10-20 cm depth changed significantly over time, whereas TN in the top 10 cm did not. Soil nutrients, and SOM and its constituents in general, commonly display vertical stratification, often exponentially decreasing with depth (Wright et al., 2007).

Similar to TN, averaged across tillage, fertility/residue level, and burn treatments, the change in soil TC:SOM over time was two times greater (*P* < 0.01; Table 1) in the top 10 cm of the soil (0.082 yr^{-1}) than in the 10-20 cm depth (0.041 yr^{-1}). Soil TC:SOM in the 10-20 cm depth significantly changed over time from 2010 to 2020. Similar to soil TN, soil SOM and TC commonly display vertical stratification, often exponentially decreasing with depth (Wright et al., 2007). However, this result indicated that, despite both TC and SOM content at least numerically decreasing with depth, as would be expected (Wright et al., 2007), and ignoring any other significant interaction of a field treatment with soil depth, soil TC content generally decreased more with depth than did SOM content.

The change in soil EC over time differed (*P* = 0.03) between tillage treatments across soil depths (Table 1). Averaged across burn and fertility/residue level treatments, the change in soil EC over time under CT in the top 10 cm was more than 1.5 times greater than that under the other three tillage-depth treatment combinations, which did not differ (Table 3). Soil EC in all four tillage-depth treatment combinations increased significantly over time from 2010 to 2020 (Table 3). Across the study site, crop residues were either left on the soil surface or shallowly incorporated into the soil. The release of nutrients from decomposing crop residues can lead to an increase in soil EC (Eigenberg et al., 2002). In addition, the groundwater used for furrow irrigation was alkaline (Norman et al., 2016; Amuri et al., 2008) and contributed to cation additions to the soil that increased in concentration as irrigation water evaporated, which also could have occurred under non-irrigated conditions by the evaporation of rainfall.

The change in soil TN:SOM ratio over time differed (P = 0.02) between burn treatments across soil depths (Table 1). Averaged across tillage and fertility/residue level treatments, the change in soil TN:SOM over time under the burn treatment in the top 10 cm of the soil was four times greater than under the burn treatment in the 10-20 cm depth (Table 3). The change in soil TN:SOM over time in the no-burn treatments were both similar to each other and similar to both burn treatments (Table 3). Soil TN:SOM in the burn/0-10 cm and the no-burn/10-20 cm treatment combinations increased significantly over time from 2010 to 2020, while the other two burn-depth combinations did not change over time (Table 3). Similar to soil TN content, soil TN:SOM ratio increased over time in the top 10 cm under burning due to the general increase in soil N in the top 10 cm coupled with lower SOM as a result of the lack of OM inputs to the soil because burning substantially reduced the potential OM input to the soil. In the no-burn treatment, nutrients, including N, and OM remained on the soil surface to decompose and be released more slowly than the little OM remaining after burning, thus limiting soil N and SOM enrichment over time, resulting in the non-significant change in TN:SOM ratio over time.

Soil EC numerically increased over time, but the increase over time also differed (P < 0.01) among tillage-burn-fertility/residue level treatment combinations (Table 1). Averaged across soil depth, the change in soil EC over time was numerically greatest in the CT-B-L treatment combination, which did not differ from that in the CT-B-H, CT-NB-H, and NT-B-H treatment combinations, and was numerically lowest in the NT-NB-H treatment combination, which did not differ from that in the CT-NB-L, NT-B-L, and NT-NB-L treatment combinations (Figure 2). Soil EC in all tillage-burn-fertility/residue level treatment combinations, except for in the NT-B-L and NT-NB-H combinations, increased significantly over time from 2010 to 2020. Tillage and residue burning are both disturbances that can accelerate decomposition and nutrient release to the soil, thereby increasing soil nutrient concentrations and soil EC. In addition, evaporation of soil water in the relatively warm and moist climate encompassing the study site coupled with a generally prominent, slightly compacted historic plow layer at ~ the 10-cm soil depth throughout the delta region of eastern Arkansas and a relatively shallow argillic horizon tends to concentrate solutes in the top 10 cm. Furthermore, soil EC generally increases over time under managed crop production (Eigenberg et al., 2002), often due to nutrient recycling as residues are returned to the soil as well as inorganic fertilizer inputs. However, these results contrast those from both Amuri et al. (2008) and Norman et al. (2016), who reported a decrease in EC over time in the top 10 cm of the soil under all treatment combinations during the first six years and then the next eight years, respectively, of the current long-term field study.

Soil BD numerically decreased over time, but the decrease over time differed ($P = 0.02$) among tillage-burn treatment combinations across soil depths (Table 1). Averaged across fertility/residue level treatments, the change in soil BD over time was numerically greatest in the CT-B treatment combination in the top 10 cm, which did not differ from that in the CT-NB and NT-NB treatment combinations in the top 10 cm. The change in soil BD over time was numerically lowest in the CT-B treatment combinations in the 10-20 cm soil depth, which did not differ from that in the CT-NB and NT-NB treatment combinations in the 10-20 cm depth (Figure 3). Soil BD in all tillage-burn-soil depth treatment combinations, except for in the CT-B and the CT-NB treatment combinations in the 10-20 cm soil depth, decreased significantly over time from 2010 to 2020. The general decrease in bulk density was at least partially due to the cumulative effects of numerically increasing SOM (Normal et al., 2016), which promotes soil structure formation and greater porosity. Compared to NT, tillage quickly incorporates surface residues, OM, and C into the soil and burning promotes quicker decomposition of belowground root biomass compared to non-burning. Results of this study were consistent with those reported by Sanford (1982) and Six et al. (1999). Similarly, Amuri et al. (2008) and Norman et al. (2016) reported an increase in bulk density in the top 10 cm under NT during the first six years and then the next eight years, respectively, of the current long-term field study.

Soil OM content in the top 10 cm of the NT-NB was the only treatment combination that significantly increased over time from 2010 to 2020, where SOM did not change over time in the other seven tillage-burn-depth treatment combinations (Figure 3). However, the change in SOM content over time differed ($P < 0.01$) among tillage-burn treatment combinations across soil depths (Table 1). Averaged across fertility/residue level treatments, the change in SOM content over time was numerically greatest in the NT-NB treatment combination in the top 10 cm, which did not differ from that in the CT-B and CT-NB treatment combinations in the top 10 cm. The change in SOM over time was numerically lowest in the NT-NB treatment in the 10-20 cm soil depth, which did not differ from that in the NT-B and CT-B treatment combinations in the 10-20 cm depth (Figure 3).

The increase in SOM in the NT-NB treatment in the top 10 cm was likely due to the organic matter that was allowed to accumulate on the soil surface. The NT treatment did not incorporate the crop residue into the soil, allowing the residue to decay and add OM to the A horizon slowly. In the NB treatment, the crop residue also remained on the soil surface, as the residue was not burned. Both the NT and NB treatments combined resulted in significantly increased SOM content in the top 10 cm. However, the SOM content in the NT-NB treatment in the top 10 cm did not differ from that in other field treatments. However, field treatments did not have the same effect in the 10-20 cm soil depth due to the lack of deeper residue incorporation into the soil. Results of the current study were similar to results of Amuri et al. (2008), who reported SOM content in the top 10 cm in the first seven years in the same plots and same field treatments of the current long-term study did not increase over time in any specific field treatment, but instead SOM content in the top 10 cm generally increased over time across all treatments combined (0.097 kg ha^{-1} yr^{-1}). Similarly, Norman et al. (2016) also reported an average increase in SOM (0.097 kg ha^{-1} yr^{-1}) in the top 10 cm across all treatments combined during years six through 14 in the same plots and same field treatments of the current long-term study.

In contrast to SOM, soil TC content, which was considered to represent all organic C (OC) since soil did not effervesce upon treatment with dilute hydrochloric acid, significantly increased over time from 2010 to 2020 in all four tillage-burn treatment combinations in the top 10 cm, but did not change over time in all four tillage-burn treatment combinations in the 10-20 cm depth interval (Figure 3). However, the change in soil TC content over time (i.e., the SOC sequestration rate) differed ($P = 0.05$) among tillage-burn combinations across soil depths (Table 1). Averaged across fertility/residue level treatments, the SOC sequestration rate was numerically greatest in the NT-NB treatment combination in the top 10 cm, which did not differ from that in the CT-B and CT-NB treatment combinations in the top 10 cm, while the SOC sequestration rate was numerically lowest in the NT-NB treatment combination in the 10-20 cm depth, which did not differ from that in the CT-B, CT-NB, and NT-B treatment combinations in the 10-20 cm depth (Figure 3).

Significant soil TC and SOC sequestration occurred in the top 10 cm in all field treatments in the top 10 cm because of the increase in SOM in the top 10 cm, which did not occur in the 10-20 cm depth. Soil OM contains a substantial fraction of C, often around 50% (NRCS, 2009), thus, when SOM breaks down, both TC and SOC tend to increase. These results are consistent with Amuri et al. (2008), who reported an increase in soil TC and SOC in the top 10 cm of the soil in the first seven years in the same plots and same field treatments of the current long-term study.

In contrast to all other measured or calculated soil properties, the change in soil pH and C:N ratio over time were unaffected by tillage, burning, fertility/residue level, or soil depth (Table 1). However, soil pH and C:N ratio in several tillage-burn-fertility-depth treatment combinations changed significantly over time. Averaged across all field treatments, soil pH decreased over time in the NT-B-H ($P = 0.05$) and NT-B-L ($P < 0.01$) treatment combinations in the top 10 cm and in the NT-B-L ($P = 0.05$) treatment combination in the 10-20 cm depth, while soil pH did not change over time in the other 13 treatment combinations. The lower pH under residue burning than non-burning may be due to increased N mineralization and nitrification, which is an acidifying process. Burning allows for greater mineralization of residues, leading to increased nitrification. The process of nitrification releases H ions into the soil, which lead to greater acidity and lower pH (Amuri et al., 2008). However, Amuri et al. (2008) reported that, for the first six years of the current long-term study, the average pH in the top 10 cm increased over time across all treatment combinations. In contrast to Amuri et al. (2008), but similar to the results of the current study, Norman et al. (2016) reported that soil pH generally decreased across all treatment combinations between years six and 14 of the current long-term study.

Averaged across all field treatments, soil C:N ratio increased significantly over time in the CT-B-H (P = 0.01) and CT-NB-H (P = 0.02) treatment combinations in the top 10 cm and in the CT-NB-L (P = 0.02) treatment combination in the 10-20 cm depth, while soil C:N ratio did not change over time in the other 13 treatment combinations. The change in soil C:N over time may be due to the more rapid decomposition of incorporated crop residues and release of C in the top 10 cm after tillage (Norman et al., 2016). In addition, even a slight decrease in soil N from increased plant N uptake and/or N leaching, coupled with the increase soil C, could have contributed to the increased soil C:N ratio. These results differ from those of Norman et al. (2016), where the soil C:N ratio decreased over time in the top 10 cm when averaged across burning, irrigation, and tillage.

Field Treatment Effects Ignoring Residue Burning

The change in all measured or calculated soil properties over time were affected by at least one of the field treatments tested (i.e., tillage, residue level, and irrigation) when the residue burning factor was ignored (Table 2). Averaged across tillage, fertility/residue level, and soil depth, the change in soil pH over time was 1.9 times greater ($P < 0.01$; Table 2) under irrigation (-0.37 units yr^{-1}) than under no irrigation (-0.72 units yr^{-1}). However, neither soil pH under irrigated or dryland conditions changed over time from 2010 to 2020. Irrigation can lead to increased soil-surface pH over time if base-cation rich groundwater or surface water is used repeatedly, such as was the case for using groundwater as the irrigation water source in the current long-term field study. Amuri et al. (2008) also reported soil pH increased over time under irrigation in the first seven years of the current long-term field study.

Averaged across tillage, fertility/residue level, and irrigation, the change in soil SOM over time was four times greater ($P < 0.01$; Table 2) in the top 10 cm of soil (4.5 Mg ha^{-1} yr^{-1}) than in the 10-20 cm depth (-1.5 Mg ha^{-1} yr^{-1}), but neither changed over time from 2010 to 2020. Similar to SOM, averaged across tillage, fertility/residue level, and irrigation, the change in soil TC over time was 9.2 times greater ($P < 0.01$; Table 2) in the top 10 cm of soil (4.6 Mg ha^{-1} yr^{-1}) than in the 10-20 cm depth (0.5 Mg ha^{-1} yr^{-1}), while neither changed over time. Similar to the increase in SOM under burning in the top 10 cm, decaying residues allow for OM and C enrichment near the soil surface, but not at deeper soil depths.

Similar to SOM and TC, averaged across tillage, fertility/residue level, and irrigation, the change in soil TN over time was 48 times greater ($P < 0.01$; Table 2) in the top 10 cm of soil (0.29 Mg ha^{-1} yr^{-1}) than in the 10-20 cm depth (< 0.01 Mg ha^{-1} yr^{-1}). However, in contrast to SOM and TC, soil TN in the top 10 cm increased significantly over time from 2010 to 2020. Much like soil TC, soil TN is also contained in SOM, thus the increase in SOM over time also tends to increase soil TN. The difference among the increase in SOM, soil TC, and soil TN was that soil TN was the only property among these three that increased over time from 2010 to 2020. This result was likely aided by the addition N fertilizer to some field treatments and the lower magnitude of TN compared to SOM and TC that was likely more sensitive to even small changes in TN.

The change in soil C:N over time differed ($P = 0.01$) between irrigation treatments across tillage treatments (Table 2). Averaged across soil depth and fertility/residue level treatments, the change in soil C:N over time under the CT-I treatment combination was at least 1.8 times greater than under the other three treatment combinations, which did not differ, while none of the four treatment combinations changed over time from 2010 to 2020 (Table 3). Like with the soil C:N ratio under the B/NB treatments, tillage tends to allow faster decomposition of SOM, releasing C and N. Irrigation could lead to nutrient runoff, resulting in varying levels of near-surface soil C and N, where these factors combined could lead to a change in soil C:N ratio.

The change in soil C:N over time also differed ($P < 0.01$) between irrigation treatments across soil depths (Table 2). Averaged across tillage and fertility/residue level treatments, the change in soil C:N over time under both irrigated treatments and the non-irrigated treatment in the top 10 cm, which did not differ, was at least 3.1 times greater than under the non-irrigated treatment in the 10-20 cm depth, while none of the four irrigation-soil depth combinations changed over time from 2010 to 2020 (Table 4). Soil C and N tend to accumulate more within the top 10 cm of the soil simply due to organic matter breakdown that mainly occurs in the upper profile near the soil surface. The greater C:N ratios under irrigated conditions was likely due to at least numerically greater increases in soil C relative to soil N from greater biomass production when water was not a limiting factor for plant productivity.

The change in soil TC:SOM over time differed ($P = 0.01$) among irrigation and tillage treatments (Table 2). Averaged across soil depth and fertility/residue level treatments, the change in soil TC:SOM over time under the NT-NI treatment combination was 1.6 times greater than under both the CT-NI and NT-I treatment combinations, which did not differ (Table 3). The change in soil CN:SOM over time in CT-I treatment was also similar to that in the other three treatment combinations (Table 3). The change in soil TC:SOM in the CT-I and the NT-NI treatment combinations increased over time, while that in the other two irrigation-tillage treatment combinations did not change over time from 2010 to 2020 (Table 3). The greater increase in TC:SOM under the NT, non-irrigated treatment was likely because the lack of soil disturbance under NT allowed for at least numerically greater soil C build-up relative to SOM, whereas CT would tend to stimulate soil C mineralization and irrigation would tend to increase both C and SOM more equally, even under NT conditions.

The change in soil TC:SOM over time also differed ($P = 0.03$) between irrigation treatments across soil depths (Table 2). Averaged across tillage and fertility/residue level treatments, the change in soil TC:SOM over time under the irrigated treatment in the top 10 cm of the soil was three times greater than under the irrigated treatment in the 10-20 cm soil depth (Table 4). The change in soil TC:SOM over time in the irrigated treatment in the top 10 cm of the soil was similar to that in the non-irrigated treatment in the top 10 cm of the soil (Table 4). The change in soil TC:SOM in all treatment combinations, except for the irrigated treatment in the 10-20 cm soil depth, increased significantly over time from 2010 to 2020 (Table 4). Much like with the TC:SOM differences averaged across soil depth and fertility/residue level, the TC:SOM ratio increased in the top 10 compared to in the 10-20 cm depth interval due to a combination of at least numerically greater accumulation of C relative to SOM nearer the soil surface, particularly under irrigated conditions that resulted in greater biomass production, and at least numerically lower SOM on account of greater overall SOM mineralization under the decomposition-favorable irrigated conditions.

Similar to TC:SOM, the change in soil TN:SOM over time differed ($P < 0.01$) between irrigation treatments across soil depths (Table 2). Averaged across tillage and fertility/residue level treatments, the change in soil TN:SOM over time under both irrigated treatments in the top 10 cm and the non-irrigated treatment in the 10-20 cm soil depth, which did not differ, were at least 3.7 times greater than under that in the irrigated treatment in the 10-20 cm soil depth (Table

4). The change in soil TN:SOM over time in the irrigated treatment in the 10-20 cm was also similar to that in the non-irrigated treatment in the top 10 cm (Table 4). The change in soil TN:SOM in all treatment combinations, except for the irrigated treatment in the 10-20 cm soil depth, increased over time from 2010 to 2020 (Table 4). Similar to TC:SOM, the TN:SOM was greater under irrigated conditions in the top 10 cm due to a combination of at least numerically greater accumulation of N, from greater biomass production, relative to SOM in plow layer and at least numerically lower SOM on account of greater SOM decomposition under wetter soil conditions from irrigation.

Soil BD decreased over time from 2010 to 2020 in all tillage-irrigation-fertility/residue level treatment combinations (Figure 2), but the change over time also differed ($P = 0.02$) among tillage-irrigation-fertility treatment combinations (Table 2). Averaged across soil depths, the change in soil BD over time was numerically greatest in the CT-I-H and numerically smallest in the CT-NI-H treatment combination (Figure 2). Despite ANOVA identifying a significant treatment interaction, means were unable to be separated among tillage-irrigation-fertility treatment combinations (Figure 2). Like soil BD in the burn treatments, the overall decrease in BD was likely due to increased SOM from greater residue inputs due to irrigation and N fertilization (Norman et al., 2016), while tillage incorporated residues to contribute to lower BD and, consequently, increased porosity from the elevated OM inputs.

Implications

Understanding the effects of different crop management practices on the soil is crucial for predicting both long- and short-term agricultural productivity and sustainability. The Lower Mississippi River delta region of eastern Arkansas has a long history of intensive (i.e., cultivated) crop management, but intense management may not be sustainable in the long-term. Less intense, alternative, and potentially more sustainable management practices may be just as productive, but also potentially more profitable in the long-term. Results of long-term studies, such as the current study, can help producers make informed decisions in order to maximize the soil longevity and enhance current and future crop productivity.

Conclusions

This long-term study in the Lower Mississippi River delta region of eastern Arkansas revealed that different crop management practices have varying effects on near-surface soil properties. Soil properties, such as BD, SOM, TC, TN, and pH, were affected by various agricultural residue and water management practices (i.e., irrigation, tillage, and fertility/residue level treatments) that also varied across soil depths. In general, BD decreased over time in both soil depths, but decreased more in the top 10 cm than in the 10-20 cm depth. As hypothesized, residue burning lowered soil nutrient contents and non-burning increased SOM, TN, and TC contents in the top 10 cm. Large fertilizer levels and irrigation both contributed to changes in soil nutrient contents and increased both soil EC and pH. Overall, each agricultural management practice studied had both positive and negative effects on near-surface soil properties. Further research will help clarify and solidify the results of this study.

References

Amuri, N., Brye, K. R., Gbur, E. E., Popp, J., & Chen, P. (2008). Soil property and soybean yield trends in response to alternative wheat residue management practices in a wheat-soybean, double-crop production system in eastern Arkansas. *Journal of Integrative Bioscience, 6,* 64–86.

National Agricultural Statistics Service (NASS). (2021). *2020 STATE AGRICULTURE OVERVIEW – Arkansas*. USDA. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=ARKANSAS

Biederbeck, V. O., Campbell, C. A., Bowren, K. E., Schnitzer, M., & McIver, R. N. (1980). Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. *Soil Science Society of America Journal, 44*, 103-111.

Brye, K. R. (2012). Long-term effects of aboveground biomass removal by burning on potential nutrient recycling. *Crop Management, 11*, 1-9.

Brye, K. R., Cordell, M. L., Longer, D. E., & Gbur, E. E. (2007). Residue management practice effects on soil surface properties in a young wheat-soybean double-crop system. *Journal of Sustainable Agriculture, 29*, 121-150.

Cambardella, C. A., & Elliot, E. T. (1993). Carbon and nitrogen distribution in aggregates from cultivated native grassland soils. *Soil Science Society of America Journal, 57*, 1071-1076.

Chan, K. Y., & Heenan, D. P. (2005). The effects of stubble burning and tillage on soil carbon sequestration and crop productivity in southeastern Australia. *Soil Use and Management, 21*, 427–431.

Cordell, M. L., Brye, K. R., Longer, D. E., & Gbur, E. E. (2006). Residue management practice effects on soybean establishment and growth in a young wheat-soybean double-cropping system. *Journal of Sustainable Agriculture, 29*, 97-120.

Daniels, M. B., & Scott, H. D. (1991). Water use efficiency of double-cropped wheat and soybean. *Agronomy Journal, 83*, 564-570.

Desrochers, J., Brye, K. R., Gbur, E., Pollock, E. D., & Savin, M. C. (2019). Long-term residue and water management practice effects on particulate organic matter in a loessial soil in eastern Arkansas, USA. *Geoderma, 337*, 792-804.

Egli, D. B. (2008). Soybean yield trends from 1972 to 2003 in mid-western USA. *Field Crops Research, 106*, 53–59.

Eigenberg, R. A., Doran, J. W., Nienaber, J. A., Ferguson, R. B., & Woodbury, B. L. (2002). Electrical conductivity monitoring of soil condition and available N with animal manure and a cover crop. *Agriculture, Ecosystems & Environment, 88*, 183-193.

Marra, M. C., & Carlson, G. A. (1986). Double-cropping wheat and soybeans in the southeast: Input use and patterns of adoption. USDA. Agricultural Economic Report Number 552.

National Oceanic and Atmospheric Administration (NOAA). (2021). Monthly, daily, annual, and hourly station normals of temperature, precipitation, and heating and cooling days 1981-2010: Marianna, Arkansas.

Natural Resource Conservation Service (NRCS). (2021). Soil quality indicators. USDA. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_019177.pdf

NeSmith, D. S., Hargrove, W. L., Radcliffe, D. E., Tollner, E. W., & Ariouglu, H. H. (1987). Tillage and residue management effects on properties of an Ultisol and double-cropped soybean production. *Agronomy Journal, 79*, 570-576.

Norman, R. C., Brye, K. R., Gbur, E. E., Chen, P., & Rupe, J. (2016). Long-term management effects on soil properties and yields in a wheat-soybean double-crop system in Eastern Arkansas. *Soil Science, 181*, 1-12.

Padgitt, M., Newton, D., Penn, R., & Sandretto, C. (2000). Production practices for major crops in US agriculture, 1990–97. *USDA/Economic Research Service Statistical Bulletin, 969*, 1–4.

Parsch, L. D., Keisling, T. C., Sauer, P. A., Oliver, L. R., & Crabtree, N. S. (2001). Economic analysis of conservation and conventional tillage cropping systems on clayey soil in eastern Arkansas. *Agronomy Journal, 93*, 1296–1304.

Sanford, J. O. (1982). Straw and tillage management practices in soybean-wheat doublecropping. *Agronomy Journal, 74*, 1032-1035.

Scott, H. D., Ferguson, J. A., Hanson, L., Fugitt, T., & Smith, E. (1998). Agricultural water management in the Mississippi Delta region of Arkansas. *University of Arkansas Research Bulletin, 959*, 14-26.

Six, J., Elliott, E. T., & Paustian, K. (1999). Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of America Journal, 63*, 1350–1358.

Smith, S. F., Brye, K. R., Gbur, E. E., Chen, P., & Korth, K. (2014). Residue and water management effects on aggregate stability and aggregate-associated carbon and nitrogen in a wheat-soybean, double-crop system. Soil Science Society of America Journal, 78, 1378-1391.

University of Arkansas Cooperative Extension Service (UACES). (2000). Arkansas soybean handbook. University of Arkansas Cooperative Extension Service, 197. https://www.uaex.edu/publications/mp-197.aspx

Web Soil Survey. (2021). USDA-NRCS. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Wright, A. L., Hons, F. M., Lemon, R. G., McFarland, M. L., & Nichols R. L. (2007). Stratification of nutrients in soil for different tillage regimes and cotton rotations. *Soil and Tillage Research, 96*, 19-27.

TABLE 1 Analysis of variance summary of the effects of tillage, fertility/residue level, residue burning, soil depth, and their interactions on the change in soil bulk density (BD), pH, electrical conductivity (EC), soil organic matter (SOM), total carbon (TC), total nitrogen (TC), C:N ratio, TC:SOM ratio, and TN:SOM ratio over time from 2010 to 2020 in a long-term, wheat-soybean, double-crop production system on a silt-loam soil in eastern Arkansas.

Treatment Effect	**Δ BD**	**Δ pH**	**Δ EC**	**Δ SOM**	**Δ TC**	**Δ TN**	**Δ C:N**	**Δ TC:SOM**	**Δ TN:SOM**
					P				
Tillage (T)	0.92	0.12	0.12	0.36	0.57	0.77	0.15	0.55	0.09
Fertility (F)	0.59	0.17	0.84	0.13	0.46	0.67	0.36	0.60	0.73
T*F	0.97	0.25	0.57	0.12	0.26	0.29	0.79	0.90	0.73
Burning (B)	0.26	0.37	< 0.01	0.06	0.37	0.02	0.98	0.88	0.73
T*B	0.22	0.23	0.15	0.27	0.33	0.16	0.40	0.47	0.57
B*F	0.50	0.45	0.17	0.89	0.77	0.67	0.51	0.44	0.30
T*B*F	0.81	0.30	< 0.01	0.29	0.60	0.83	0.57	0.63	0.57
Depth (D)	< 0.01	0.31	< 0.01	< 0.01	< 0.01	< 0.01	0.10	< 0.01	0.30
T*D	< 0.01	0.18	0.03	0.48	0.69	0.67	0.83	0.41	0.42
F*D	0.54	0.51	0.95	0.60	0.57	0.17	0.13	0.46	0.21
T*F*D	0.59	0.61	0.58	0.61	0.18	0.60	0.16	0.73	0.91
B*D	0.37	0.25	0.38	< 0.01	0.03	0.06	0.71	0.39	0.02
T*B*D	0.02	0.21	0.08	< 0.01	0.05	0.14	0.13	0.83	0.91
B*F*D	0.68	0.62	0.99	0.39	0.62	0.34	0.65	0.28	0.14
T*B*F*D	0.46	0.65	0.13	0.66	0.31	0.17	0.50	0.12	0.57

TABLE 2 Analysis of variance summary of the effects of tillage, fertility/residue level, irrigation, soil depth, and their interactions on the change in soil bulk density (BD), pH, electrical conductivity (EC), soil organic matter (SOM), total carbon (TC), total nitrogen (TC), C:N ratio, TC:SOM ratio, and TN:SOM ratio over time from 2010 to 2020 in a long-term, wheat-soybean, double-crop production system on a silt-loam soil in eastern Arkansas.

Treatment Effect	**Δ BD**	**Δ pH**	**Δ EC**	**Δ SOM**	**Δ TC**	**Δ TN**	**Δ C:N**	**Δ TC:SOM**	**Δ TN:SOM**
					P				
Tillage (T)	0.91	0.12	0.12	0.36	0.49	0.79	0.07	0.48	0.09
Fertility (F)	0.58	0.18	0.79	0.09	0.39	0.70	0.27	0.60	0.73
T*F	0.97	0.27	0.61	0.08	0.19	0.30	0.74	0.90	0.73
Irrigation (I)	0.89	< 0.01	0.50	0.17	0.48	0.42	0.16	0.58	0.30
T*I	0.21	0.94	0.64	0.84	0.10	0.47	0.01	0.01	0.42
I*F	0.19	0.80	0.74	0.16	0.47	0.61	0.37	0.96	0.91
T*I*F	0.02	0.50	0.15	0.25	0.86	0.61	0.36	0.66	0.56
Depth (D)	< 0.01	0.32	< 0.01	< 0.01	< 0.01	< 0.01	0.09	< 0.01	0.30
T*D	< 0.01	0.19	0.05	0.53	0.73	0.68	0.83	0.40	0.42
F*D	0.54	0.52	0.96	0.65	0.62	0.18	0.12	0.45	0.21
T*F*D	0.60	0.62	0.62	0.66	0.23	0.61	0.15	0.72	0.91
I*D	0.28	0.27	0.08	0.41	0.35	0.08	< 0.01	0.03	< 0.01
T*I*D	0.54	0.78	0.15	0.74	0.86	0.92	0.25	0.19	0.73
I*F*D	0.40	0.72	0.87	0.74	0.88	0.30	0.77	0.33	0.73
T*I*F*D	0.21	0.94	0.74	0.64	0.90	0.54	0.69	0.57	0.73

TABLE 3 Summary of the interactive effects of tillage [conventional tillage (CT) and no-tillage (NT)]/burn and soil depth/irrigation on the change in soil electrical conductivity (ΔEC), total nitrogen:soil organic matter ratio (ΔTN:SOM), total carbon:total nitrogen ratio (ΔC:N), and total carbon:soil organic matter ratio (ΔTC:SOM) over time from 2010 to 2020 in a long-term, wheat-soybean, double-crop production system on a silt-loam soil in eastern Arkansas.

Soil Property	Tillage/Burn Treatment	Depth (cm)/Irrigation Treatment	Mean[†]
ΔEC	CT	0-10	0.071 a*
(yr^{-1})	CT	10-20	0.046 b*
	NT	0-10	0.039 b*
	NT	10-20	0.036 b*
ΔTN:SOM	Burn	0-10	0.008 a*
(yr^{-1})	Burn	10-20	0.002 b
	No burn	0-10	0.003 ab
	No burn	10-20	0.005 ab*
ΔC:N	CT	Irrigated	1.61 a
(yr^{-1})	CT	Non-irrigated	0.74 b
	NT	Irrigated	0.65 b
	NT	Non-irrigated	0.90 b
ΔTC:SOM	CT	Irrigated	0.07 ab*
(yr^{-1})	CT	Non-irrigated	0.05 b
	NT	Irrigated	0.05 b
	NT	Non-irrigated	0.08 a*

[†] Means with different letters within a soil property are different at $P < 0.05$. Positive values indicate an increase over time.

* An asterisk (*) indicates the mean value differs from 0 at $P < 0.05$.

TABLE 4 Summary of the interactive effects of irrigation and soil depth on the change in total carbon:total nitrogen ratio (ΔC:N), total carbon:soil organic matter ratio (ΔTC:SOM), and total nitrogen:soil organic matter ratio (ΔTN:SOM) over time from 2010 to 2020 in a long-term, wheat-soybean, double-crop production system on a silt-loam soil in eastern Arkansas.

Irrigation	**Depth (cm)**	**ΔC:N† (yr^{-1})**	**ΔTC:SOM† (yr^{-1})**	**ΔTN:SOM† (yr^{-1})**
Irrigated	0-10	1.02 a	0.089 a*	0.0071 a*
Irrigated	10-20	1.24 a	0.028 c	< 0.001 b
Non-irrigated	0-10	1.30 a	0.075 ab*	0.0037 ab*
Non-irrigated	10-20	0.33 b	0.054 bc*	0.0071 a*

† Means with different letters within a soil property are different at $P < 0.05$. Positive values indicate an increase over time.

* An asterisk (*) indicates the mean value differs from 0 at $P < 0.05$.

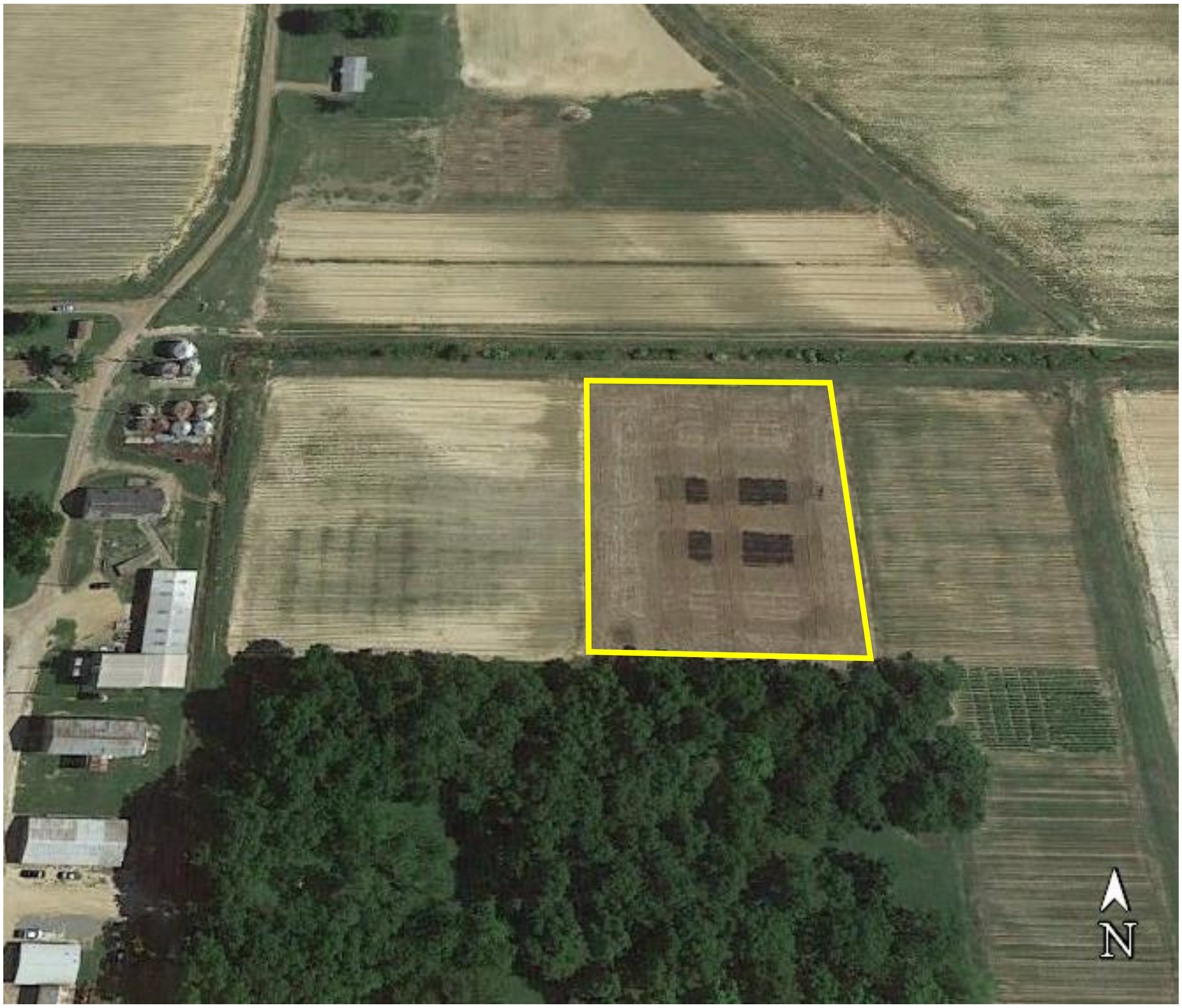

Figure 1. Aerial view of the study site at the Lon Mann Cotton Branch Experiment Station near Marianna, Arkansas.

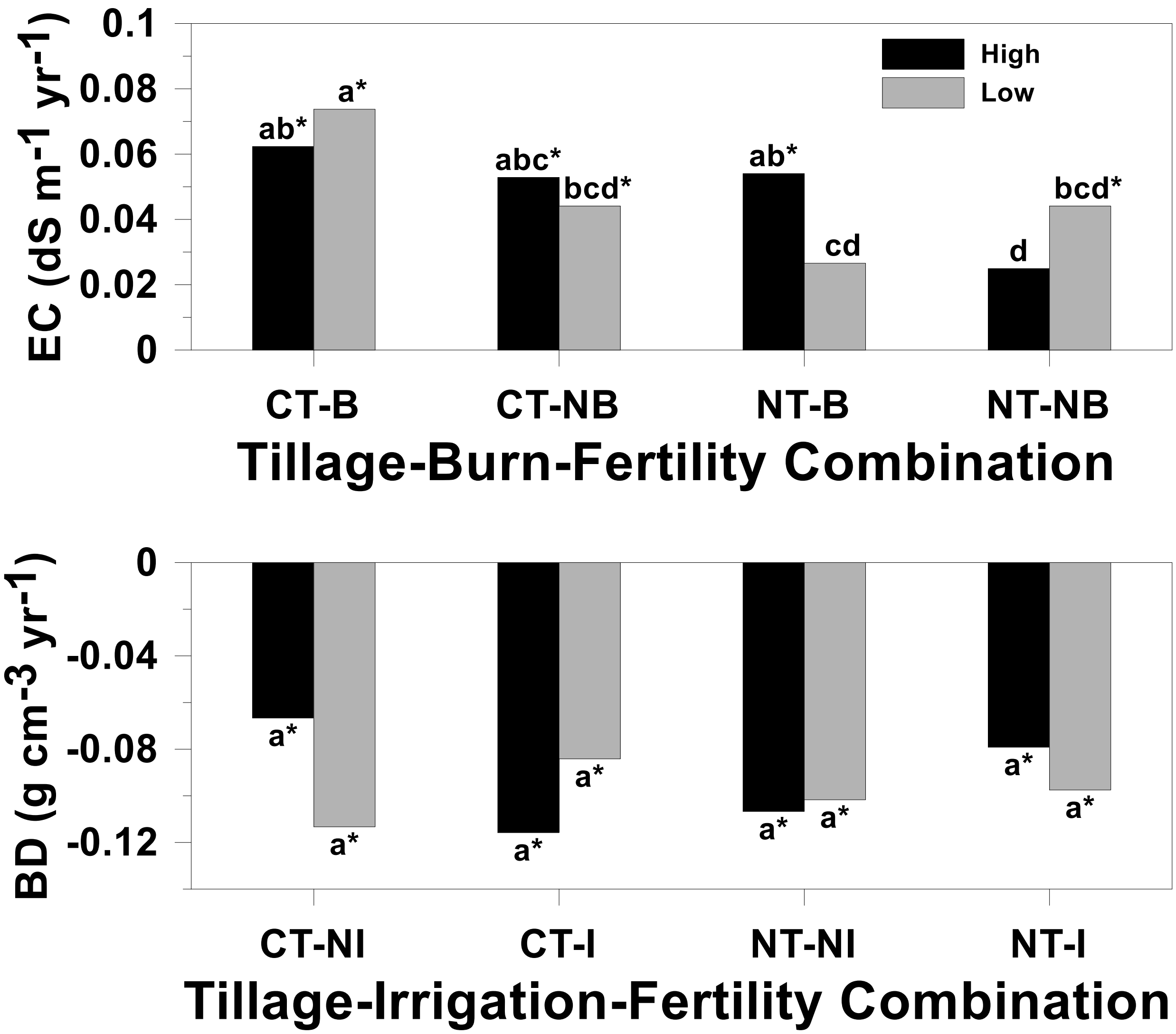

Figure 2. Summary of the interactive effects of tillage [conventional tillage (CT) and no-tillage (NT)], burning [burning (B) and non-burning (NB)] or irrigation [irrigation (I) and non-irrigated (NI)], and fertility [high (H) and low (L) wheat residue level achieved with differential nitrogen application] on the change in electrical conductivity (EC) and bulk density (BD) over time from 2010 to 2020 in a long-term, wheat-soybean, double-crop production system on a silt-loam soil in eastern Arkansas. Positive values indicate an increase, while negative values indicate a decrease over time. Lower case letters atop bars within a panel are different at $P < 0.05$. Asterisks (*) indicate the mean change for a treatment combination differs from 0 at $P < 0.05$.

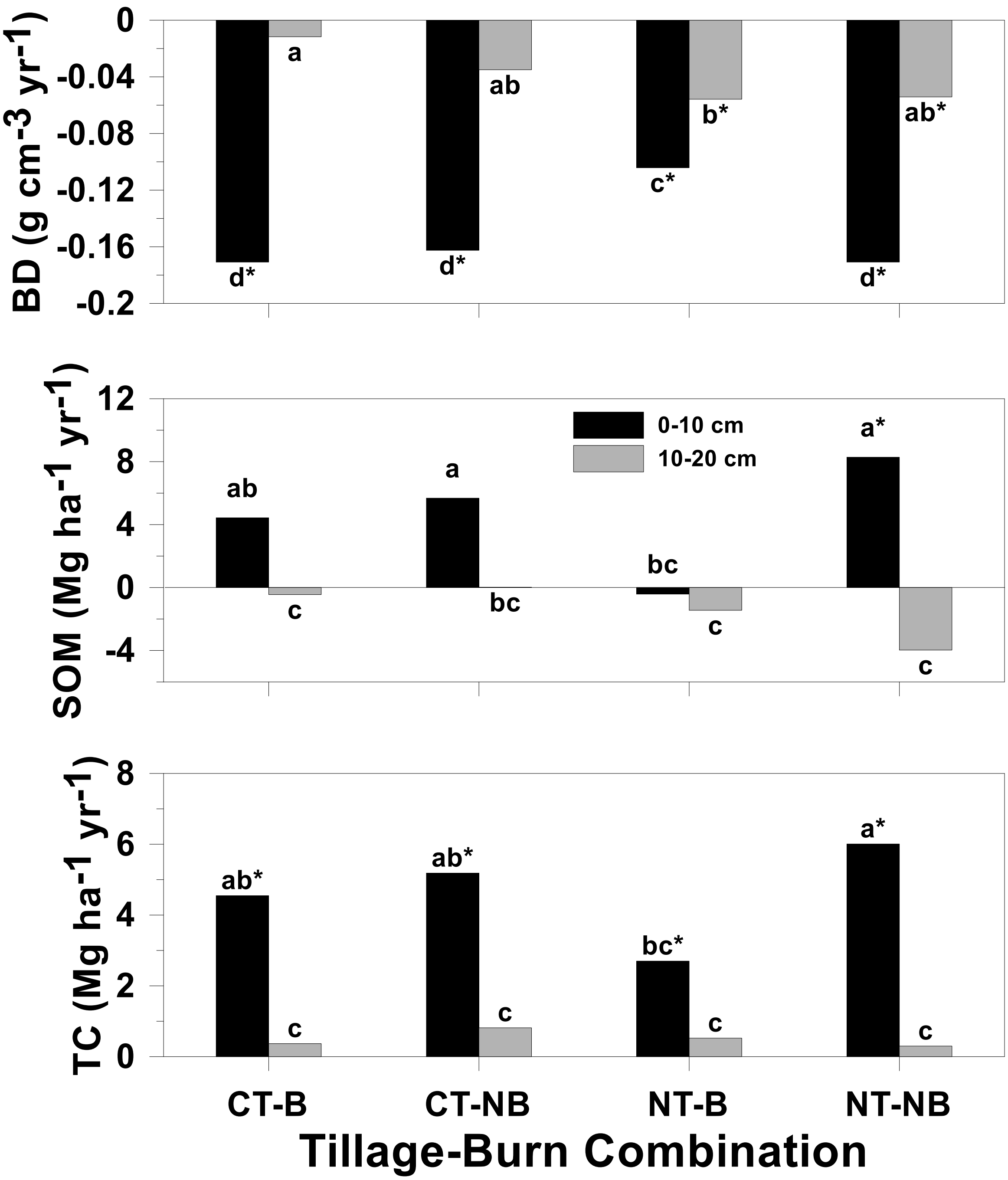

Figure 3. Summary of the interactive effects of tillage [conventional tillage (CT) and no-tillage (NT)] and burning [burning (B) and non-burning (NB)] on the change in bulk density (BD), soil organic matter (SOM), and total carbon (TC) across soil depths over time from 2010 to 2020 in a long-term, wheat-soybean, double-crop production system on a silt-loam soil in eastern Arkansas. Positive values indicate an increase, while negative values indicate a decrease over time. Lower case letters atop bars within a panel are different at $P < 0.05$. Asterisks (*) indicate the mean change for a treatment combination differs from 0 at $P < 0.05$.