Long-term Management Effects on Soil Properties and Yields in a Wheat-Soybean Double-Crop System in Eastern Arkansas

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Abstract: The sustainability of soil and water resources in regions of highly productive row-crop agriculture depends on long-term implications of agricultural management decisions. Residue management can strongly affect soil organic matter (SOM), soil C, and other near-surface physical and chemical properties in agricultural soils, especially in double-crop systems. The objective of this study was to determine the long-term trends in SOM, soil C and N, bulk density, pH, electrical conductivity, and Mehlich-3–extractable nutrients in the top 10 cm and yield as affected by alternative residue and water management practices in a wheat (*Triticum aestivum* L.)-soybean (*Glycine max* (L.) Merr.) double-crop production system. The field site resides on a loessial soil (fine silty, mixed, active, thermic Glossaquic Fraglossudalf) in the Lower Mississippi River Alluvial Valley of eastern Arkansas and has been consistently managed for 13 years between Fall 2001 and Fall 2014. Averaged across all other treatment factors, SOM content did not change ($P > 0.05$) between 6 and 13 years after conversion to alternative management practices under irrigation, whereas SOM content increased across time ($P < 0.05$) until approximately 9 years after initial conversion then decreased thereafter under dryland production. Soil C content generally increased, P content generally decreased, and N and Cu contents and soybean yields changed little across time because of irrigation. Across time, SOM and C contents decreased ($P < 0.05$) under residue burning but increased under nonburning. The results of this study indicate that irrigation management and residue burning were responsible for many of the largest differences in near-surface soil property trends across time. Understanding the long-term effects of alternative, compared with traditional, management practices is critical to developing sustainable agricultural practices in the mid-southern United States.

Key Words: Sustainability, long-term trends, residue management, soil properties

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An understanding of how different agricultural management practices impact soil organic matter (SOM), soil C, other various soil properties, and crop yield is essential for determining sustainable practices for food production. The Intergovernmental Panel on Climate Change concluded that agriculture generates 10 to 12% of total global anthropogenic emissions of greenhouse gases (IPCC, 2013) through the burning of fossil fuels and the oxidation of SOM. Management of crop residues can strongly affect the fate of SOM in agricultural soils, as well as a host of other soil physical and chemical properties, which has implications for crop production in the short-term as well as sustainability in the long-term.

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The balance of SOM is determined by how much biomass is added to the system and the timeline of decomposition. Biomass inputs primarily consist of plant residue as well as animal and microbial tissues. Management factors such as tillage, burning, fertilization, and irrigation may influence the rate at which microbes convert organic residues into stabilized fractions of SOM as well as the rate at which microbes decompose SOM by altering the physical and chemical soil environment.

Tillage homogenizes the plow layer and alters the near-surface soil environment, which can have cumulative effects on various soil physical and chemical properties. Conventional tillage (CT) disturbs all of the soil surface and leaves less than 15% residue cover, whereas no-tillage (NT) leaves the soil undisturbed after harvest and causes minimal disturbance before and during planting (CTIC, 2014). Conventional tillage systems for soybean production in the Lower Mississippi River Alluvial Valley usually involve disking the field, followed by harrowing, with the goal of creating a fine seedbed that contains less than 15% residue on the surface to facilitate soybean planting (Padgitt et al., 2000).

Compared with NT, CT offers tangible immediate advantages by preparing finer seedbeds, reducing the need for herbicides, and improving seedling germination (Chan and Heenan, 2005). However, NT offers long-term benefits by increasing SOM accumulation, reducing the number of field passes with equipment, which is economic and fuel savings, reducing soil erosion, and reducing greenhouse gas emissions (Horowitz, 2011; Morgan et al., 2010; Padgitt et al., 2000; Verkler et al., 2009; Zanatta et al., 2007). Weighing the immediate benefits to a crop against the long-term benefits to the soil resource used for agricultural production is key to selecting the most appropriate residue management and tillage systems.

Burning crop residues is an alternative residue management practice often conducted with tillage, which can also have cumulative effects on various soil properties. Burning wheat (*Triticum aestivum* L.) residue in wheat-soybean (*Glycine max* (L.) Merr.) double-crop production systems is a widespread practice in the mid-southern United States (Frederick et al., 1998; Sanford, 1982). In wheat-soybean double-crop systems, producers will typically burn wheat residue immediately before planting soybean as a means to control weed populations and prepare a proper seedbed. The burned residue creates what is sometimes called the ash-bed effect (Chan and Heenan, 2005). As documented in a wheat-fallow study conducted on a clay-loam Luvisol and a sandy-loam Alfisol in New South Wales, Australia, the ash-bed effect is associated with increased soil pH and K (Chan and Heenan, 2005). However, residue burning can negatively impact SOM because of the lost opportunity to add OM to the soil. Moreover, burning can lead to a gradual decrease in plant-available nutrients. Burning quickly releases plant-available inorganic nutrients such as N and P but may inflict a slowly cumulative loss of N, P, and S across time (Biederbeck et al., 1980).

In addition to tillage and residue burning, N fertilization is a common management practice that promotes wheat biomass and yield. Split applications of N are particularly effective because the loss of N through leaching and denitrification is reduced and therefore plant N uptake is increased (Sripada and Weisz, 2009). Although a positive correlation exists between N fertilization and wheat biomass, the effects of N fertilization on SOM, soil C, and other soil chemical properties are more complex at least partly because of the various implications of increased N on residue decomposition and microbial activity (Banger et al., 2010; Högberg et al., 2007; Lee and Jose, 2003). Bowman and Halvorson (1998) reported a 40% increase in soil C in the top 5 cm under increased N fertilization management. Likewise, after 10 years of consistent management of a Great Plains Weld silt loam (Aridic Argiustoll) in a rotation that included winter wheat, soil organic C increased more in a high (134 kg N ha^{-1} $year^{-1}$) than in low N fertilization treatments (i.e., 0–45 kg N ha^{-1} $year^{-1}$; Halvorson et al., 1999). Banger et al. (2010) suggested that N fertilizers may preferentially stimulate the activity of certain microbes while inhibiting the development of others, such as lignin decomposers.

Another potential effect of N fertilization in excess of actual crop requirements is soil acidification. Although few N fertilizers themselves are acidic, many N fertilizers encourage acid-forming reactions (i.e., nitrification; Barak et al., 1997). In a 3-year NT wheat-corn (*Zea mays* L.)-fallow rotation study on a Great Plains Platner loam (Aridic Paleustoll) , Bowman and Halvorson (1998) reported a significant correlation between increased N fertilization and a reduction in soil pH (6.5 to 5.1) in the top 5 cm.

Similar to N fertilization, properly applied irrigation can greatly increase crop yields. Between 1972 and 2003, the mean yield of irrigated soybean in Arkansas was estimated to be 2.5 Mg ha^{-1} compared with the dryland average yield of 1.5 Mg ha^{-1} (Egli, 2008). Consequently, the majority of soybean producers in Arkansas choose to irrigate during the growing season. However, irrigation also incurs added costs and can sometimes be less profitable than nonirrigated production (Parsch et al., 2001; Verkler et al., 2009). Moreover, water is an increasingly precious resource in the Lower Mississippi River Alluvial Valley, particularly in eastern Arkansas, and irrigation may become cost prohibitive in the near future. According to Scott et al. (1998), available water in the Alluvial aquifer, the shallowest aquifer underlying much of the irrigated crop area in eastern Arkansas, will be exhausted by 2050 because of years of crop irrigation withdrawals that have exceeded the recharge rate.

Irrigation alters the soil moisture environment, thereby affecting the activity of plants and soil microorganisms and the cycling of SOM. Increased soil moisture promotes the development of plant and microbial biomass, which can contribute to an overall increase in SOM. However, increased soil moisture also promotes the microbial decomposition of SOM and slaking of unstable soil aggregates (Churchman and Tate, 1986; Six et al., 1999), which can contribute to an overall decrease in SOM. Therefore, the effects of irrigation on SOM cycling can be difficult to predict.

The effects of residue management on SOM and soil C have been previously studied in the Lower Mississippi River Delta region of eastern Arkansas (Brye et al., 2004; Motschenbacher et al., 2014). In a comparison study of various silt-loam soils in the Ozark Highlands and Grand Prairie regions in Arkansas, Brye et al. (2004) reported significantly greater total soil C, C:N ratios, and SOM concentrations in the upper 10 cm in the Ozark Highlands region. The increased soil C and SOM accumulation were attributed to climatic factors, rather than parent material. On a Dewitt silt loam (Typic Albaqualf) in eastern Arkansas, Motschenbacher et al. (2014) reported no difference in soil C between NT and CT treatments in the top 10 cm after 11 years of consistent management. However, Motschenbacher et al. (2014) reported 15 to 28% greater soil C content in high residue (i.e., winter wheat)–containing rotations compared with low residue–containing rotations.

When eastern Arkansas was covered by forested wetlands, the soils accumulated large concentrations of OM and C (Stanturf et al., 2000). Years of cultivated agriculture, however, have reduced SOM and C concentrations in the top 12 cm of cropland soil to approximately 2.1 and 1.1%, respectively (DeLong et al., 2003) compared with 4.6 to 6.5% SOM and 2.3 to 3.2% C in undisturbed prairie soils (Brye and Pirani, 2005). Consequently, adopting agricultural management practices that slow or even reverse losses of SOM and soil C are imperative for long-term agricultural sustainability, particularly in the Delta region of eastern Arkansas. Therefore, the objective of this study was to determine trends in soil properties of the top 10 cm and yield as affected by residue and water management practices between 6 and 13 years after initial conversion to alternative management in a wheat-soybean double-crop production system on a loessial soil in the Delta region of eastern Arkansas. It was hypothesized that SOM, C, and extractable soil nutrients would generally increase under nonburning compared with residue burning and that SOM, C, and extractable soil nutrients would generally increase under NT compared with CT. It was hypothesized that SOM and soybean yield would generally increase under irrigated compared with dryland management, and that SOM and soil C would generally increase more under a high than a low N fertilization rate.

MATERIALS AND METHODS

Site Description

A long-term field study was initiated in Fall 2001 at the Lon Mann Cotton Branch Experiment Station (N34°44′2.26″, W90°45′51.56″; Cordell et al., 2007) in east-central Arkansas near Marianna. The study site is located within the Southern Mississippi Valley Loess (Major Land Resource Area (MLRA) 134; Brye et al., 2013), which consists of a series of loess-covered hills and alluvial terraces. The field site is on a Calloway silt loam (fine silty, mixed, active, thermic Glossaquic Fraglossudalf; NRCS, 2015), which has 16% sand, 73% silt, and 11% clay in the top 10 cm (Brye et al., 2006). The 30-year mean annual temperature and precipitation of the region are 15.6°C and 128 cm, respectively, whereas the maximum and minimum air temperatures are 32.8°C in July and 2.4°C in January (NOAA, 2002).

Experimental Design

The original study used a 3-factor, split-strip-plot, randomized complete block experimental design with six replications of eight treatment combinations (Cordell et al., 2007). The three factors were (i) N fertilization/residue level (high (H), achieved with a split application of N fertilizer, or low (L), achieved with minimal to no N additions); (ii) residue burning (burning (B) or nonburning (NB)); and (iii) tillage (CT or NT) (Cordell et al., 2007). In 2005, an irrigation factor was introduced when the original study area was divided into two irrigated (I) and two nonirrigated (NI; i.e., dryland) blocks (Verkler et al., 2009). Since 2005, a levee was constructed each year to exclude furrow irrigation water from the dryland treatment, which received only natural rainfall, whereas furrow irrigation continued annually as needed in the irrigated treatment. Consequently, since 2005, the experimental area has consisted of 48 3 × 6–m plots with six replications for every N fertilization/residue level–burning–tillage treatment combination and three replications for every N fertilization/residue level–burning–tillage–irrigation treatment combination (Fig. 1; Amuri et al., 2008).

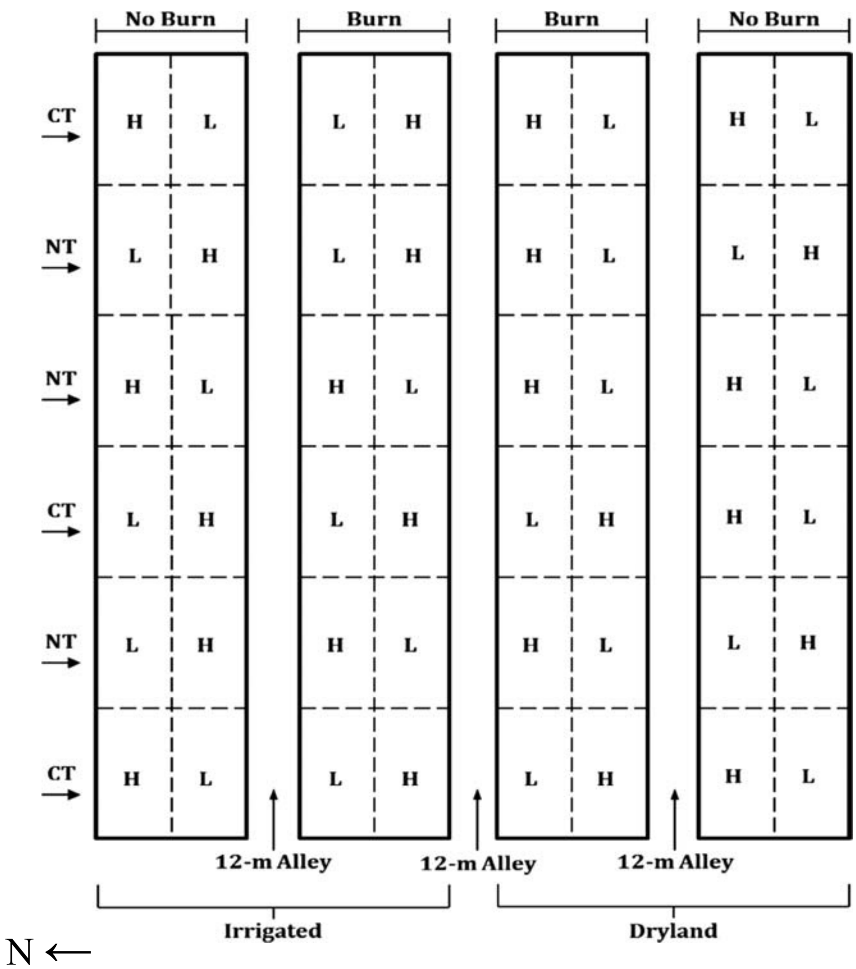

FIG. 1. Experimental layout at the Lon Mann Cotton Branch Experiment Station near Marianna in eastern Arkansas depicting 48 3 × 6–m plots subjected to residue level (high (H) and low (L)), burn, tillage (conventional tillage (CT) and no-tillage (NT)), and irrigation treatments.

Field Plot Management

Before the initiation of this study in Fall 2001, the site was managed as a continuous monocropped soybean system using CT (Cordell et al., 2007). Between 2001 and 2013, wheat was drill seeded with a 19-cm row spacing each fall. In early March 2002 through 2004, all plots were manually broadcast fertilized with urea (46% N) at the rate of 101 kg N ha^{-1}. To produce different levels of wheat residue, high-residue plots (n = 24) were manually broadcast fertilized in late March at approximately the late-jointing stage with an additional 101 kg N ha^{-1}. No N fertilizer was applied in Spring 2005 because the wheat stand failed to establish because of prolonged wet soil conditions in Fall 2004. Since 2006, the high-residue plots received an initial broadcast application of 56 kg N ha^{-1} as urea in approximately late February, followed by a split application of an additional 56 kg N ha^{-1} at the late jointing stage in approximately late March, roughly 1 month later. The low-residue plots (n = 24) have not received any N fertilization since 2006 to achieve the desired residue level difference.

In approximately early June each year between 2002 and 2014, wheat was harvested using a plot combine. Immediately after wheat harvest, wheat residue left behind after harvest of each plot was uniformly spread by hand back over each plot. All residues were mowed with a rotary mower to a height of 7 to 10 cm from the soil surface to achieve a uniform residue-covered surface for soybean planting. After mowing, the burn treatment was imposed on half of the plots by propane flaming. In 2005, 2007, and 2012, the burn treatment was not imposed because of the absence of a wheat stand in Spring 2005, prolonged wet soil conditions in Spring 2007, and overly weedy conditions in 2012. The burn treatment was followed by the tillage treatment each year. The CT plots were disked at least twice with a tandem disk to a depth of approximately 10 cm, followed by seedbed smoothing with at least three passes of a soil conditioner, representative of widely used pre–soybean-planting tillage operations throughout the region.

In approximately mid-June, a glyphosate-resistant soybean cultivar, maturity group 5.3 or 5.4, was drill seeded with 19-cm row spacing at a rate of approximately 47 kg seed ha^{-1}. Potassium fertilizer was applied according to recommended rates (UACES, 2000) based on soil test results from the previous year. In 2002 through 2004, all plots were furrow irrigated as needed, three to four times each soybean-growing season. Weeds and insects were managed annually uniformly throughout the entire study area based on University of Arkansas Cooperative Extension Service recommendations, which generally consisted of herbicide and insecticide applications during wheat- and soybean-growing seasons

(UACES, 2000). In late October to early November, soybeans were harvested with a plot combine. Soybean residue was left in place, and the subsequent wheat crop was sown to begin the next cropping cycle.

Soil Sample Collection And Processing

Between 2002 and 2008, after wheat harvest and before residue burning, 10 soil cores from the top 10 cm were collected in each plot and combined into a single composite sample. After 2008, a single soil sample was randomly collected between wheat maturity and residue burning from the top 10 cm of each plot using a 4.8-cm-diameter stainless steel core chamber. Soil samples were oven-dried for 48 h at 70°C, weighed to determine bulk density, and then ground to pass through a 2-mm mesh screen (Verkler et al., 2009) for chemical analyses (Brye et al., 2006). Soil pH and electrical conductivity (EC) were determined potentiometrically using an electrode in a 1:2 (wt/vol) soil-to-water suspension. Soil OM was determined by weight-loss-on-ignition after 2 h at 360°C. Total soil C and N were determined by high-temperature combustion with a LECO CN-2000 analyzer (LECO Corp., St. Joseph, MI) or an Elementar VarioMAX Total C and N Analyzer (Elementar Americas Inc., Mt. Laurel, NJ). All soil C was assumed to be organic because soil of the upper solum did not effervesce on treatment with dilute hydrochloric acid (Brye et al., 2006). The soil C:N ratio and C fraction of SOM were calculated from measured C and N concentrations. In addition, soil was extracted with Mehlich-3 extractant solution in a 1:10 (wt/vol) soil–to–extractant solution ratio (Tucker, 1992) and analyzed for extractable nutrients (i.e., P, K, Ca, Mg, S, Fe, Na, Mn, Cu, and Zn) by inductively coupled argon-plasma spectrophotometry (CIROS CCD model; Spectro Analytical Instruments, MA). Soil pH, EC, SOM, C, N, and the suite of extractable nutrients were chosen for evaluation because of their immediate and most relevant significance to agronomic productivity, particularly in Arkansas. All measured soil elemental concentrations (in milligrams per kilogram) were converted to contents (in kilograms per square meter or kilograms per hectare) using measured bulk density and 10-cm sample depth interval.

Soil samples were also collected between approximately 8 and 10 weeks after soybean planting to assess field treatment effects on soil bulk density. A single 4.8-cm-diameter soil core was randomly collected from each plot with a chamber beveled to the outside to minimize compaction and a slide hammer from the top 10 cm using methods outlined by Brye et al. (2006). Mid-season soil cores were oven-dried at 70°C for 48 h and weighed.

Plant Sample Collection And Processing

All wheat and soybean grain harvested from the middle 1.5-m of each plot was collected after mowing and before burning from within a 0.25-m^2 metal frame, oven-dried for 3 to 7 days at 55°C, and weighed to obtain an estimate of aboveground residue mass. Wheat and soybean grain were air-dried for approximately 3 weeks and weighed. Wheat and soybean yields were determined by oven-drying air-dried grain subsamples for 48 h at 70°C, reweighing, and adjusting to 13% moisture content for yield reporting.

Statistical Analyses

Amuri et al. (2008) reported on the trends in near-surface soil properties from Year 1 (2002) through Year 6 (2007) after conversion to alternative residue management practices. Therefore, the data set analyzed for this study consisted of soil and plant properties from Year 6 (2007) through Year 13 (2014) after conversion to alternative management practices.

To assess the validity of including and testing the N fertilization/residue level treatment, an analysis of variance was conducted by year on aboveground residue masses from annual measurements conducted between 2007 and 2014 using SAS (version 9.3; SAS Institute, Inc., Cary, NC). Means were separated by least significant difference (LSD) at the 0.05 level.

To assess long-term (i.e., 2007–2014) trends in near-surface soil properties and crop yields, an analysis of covariance (ANCOVA) was conducted using SAS to determine the effects of residue level, burning, tillage, irrigation, and their interactions on the relationship between annual soil and plant properties (dependent variables) during the period 2007 through 2014 (independent variable). Although the actual experimental design in the field was a strip-split-plot randomized complete block (Fig. 1) to facilitate the ANCOVA, the experimental design was assumed to be completely random, with three replications of each of 16 field treatment combinations. The full ANCOVA model, which initially consisted of a linear, quadratic, and intercept term each depending on the model factor combinations, was reduced using a hierarchical principle to remove nonsignificant terms, except when nonsignificant terms participated in higher-order complex treatment interactions. When appropriate, regression coefficient estimates for the linear and quadratic terms only were separated by LSD at the 0.05 level.

RESULTS AND DISCUSSION

Assessment Of Annual Residue Levels

Although actual residue amounts varied by year, the high N fertilization rate achieved a greater residue level than the low N fertilization rate during the period considered (2007–2014). In addition, a significantly ($P < 0.05$) greater residue mass was achieved with the high compared with the low N fertilization rate in 7 of the 8 years, the exception being in 2010 after 9 years of consistent residue management. Therefore, inclusion and formal testing of the N fertilization/residue level treatment were justified.

Soil Property And Soybean Yield Trends Across Time

Because the data set consisted of annual soil and plant properties measured between 6 and 13 years after initial conversion to alternative management practices, only the linear and quadratic terms in the reduced ANCOVA model were formally evaluated for each variable. The initial soil properties and crop yields from Year 1 after initial conversion to alternative management practices have been analyzed and reported previously (Brye et al., 2006; Cordell et al., 2007). In addition, the intercept terms (i.e., the values of measured properties at Year 0) for these soil and plant properties have already been assessed in a previous study that evaluated trends between Year 1 (2002) and Year 6 (2007) after initial conversion (Amuri et al., 2008). The regression intercepts for soil properties were generally uniform in the top 10 cm across field treatments, with only a few exceptions. Intercept terms for extractable soil Mg and P were greater for the burn than the no-burn treatment, and the intercept term for soil pH was greater for the no-burn than the burn treatment (Amuri et al., 2008). Regression intercepts were previously evaluated and will not be presented or discussed in this work, whose primary objective was to analyze the trends of soil properties taking place between 6 and 13 years after initial conversion to alternative management practices.

Bulk Density

During the course of seven complete wheat-soybean cropping cycles (i.e., 2007–2014), after six previous complete cropping cycles (i.e., 2001–2007) after conversion to alternative

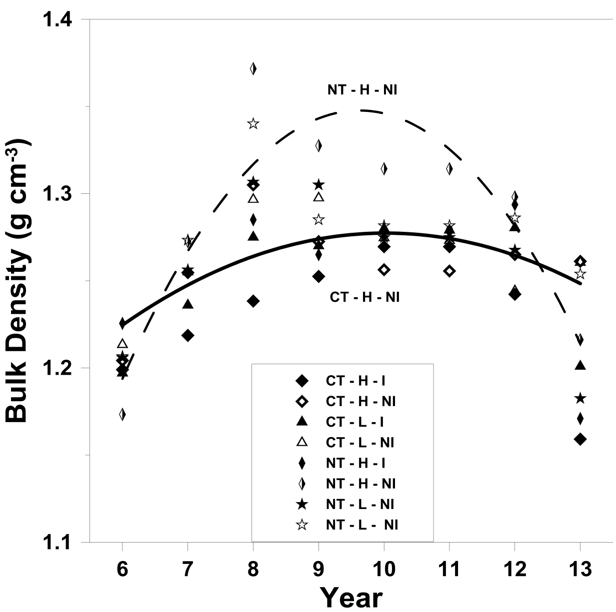

FIG. 2. Influence of tillage (conventional tillage (CT) and no-tillage (NT)), N fertilization/residue level (high (H) and low (L)), and irrigation (irrigated (I) and nonirrigated (NI)) on bulk density in the top 10 cm between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas.

management practices, the trend in bulk density in the top 10 cm across time was affected ($P < 0.05$) by all field treatment factors evaluated. Near-surface bulk density in all treatment combinations increased until approximately 9 years after initial conversion, then decreased thereafter (Fig. 2). The largest and most obvious differences, based on an interpretation of the LSD among regression coefficients, occurred between tillage–N fertilization/residue level–irrigation treatment combinations. Clear differences existed between CT and NT treatments under high-residue nonirrigated production. Averaged across burning, bulk density increased ($P < 0.001$) under the NT-H-NI at approximately three times the rate of increase under the CT-H-NI treatment combination. Approximately 9 years after initial conversion, bulk density began to decrease ($P < 0.001$) under the NT-H-NI at a greater rate than under the CT-H-NI treatment combination. Results suggest that the effects of soil compaction under the weight of equipment for routine field operations exceeded the effects of improved soil structure (i.e., decrease in bulk density) associated with NT management. These results are consistent with an 11-year corn study in Central Canada that reported 10% greater bulk density in NT than in CT in the top 10 cm (Dam et al., 2005). However, these results are in contrast with an 8-year winter wheat study near El Reno, Oklahoma, that reported decreased near-surface bulk density under NT compared with CT (Dao, 1993).

The measured bulk densities from spring soil sampling were used as part of the calculation to convert measured soil elemental concentrations (in milligrams per kilogram) into contents (in kilograms per square meter). Therefore, the effects of field treatments on bulk density are embedded in all following soil content trends.

Som, C, And N

Similar to bulk density, trends in SOM, C, and N contents in the top 10 cm were affected ($P < 0.05$) by all field treatment factors evaluated, but most clearly affected by irrigation. Averaged across tillage, burning, and N fertilization/residue level, SOM content increased at a rate of 0.56 kg m^{-2} year^{-1} ($P < 0.001$) under dryland production until approximately 9 years after initial conversion, then decreased at a rate of 0.03 kg m^{-2} year^{-1} thereafter (Fig. 3). In contrast, there was no change ($P > 0.05$) in SOM content under irrigation, which averaged 2.87 kg m^{-2} throughout the study period. Consequently, the hypothesis that SOM content would increase under irrigated conditions was not supported. These results are also in contrast to results analyzed from the first 6 years after conversion to new management practices, where SOM in the top 10 cm was unaffected by tillage, burning, and N fertilization/residue level but increased across all treatments at an average rate of 0.097 kg m^{-2} year^{-1} likely caused by the conversion from a monoculture to a more diverse crop rotation (Amuri et al., 2008).

Irrigation strongly affects the activity of plants and soil microorganisms, leading to changes in SOM formation and decomposition. Whereas increased soil moisture can increase SOM and soil C by promoting the development of plant and microbial biomass, increased soil moisture also promotes microbial decomposition of SOM and respiration losses of C (Churchman and Tate, 1986). For example, Linn and Doran (1984) reported increased soil respiration associated with increased soil moisture up to 60% water-filled pore space, beyond which microbial activity and respiration decreased in the upper 7.5 cm in a continuous corn and wheat-fallow study conducted on several silt-loam, loam, and clay-loam soils across the eastern United States. Similarly, the results of this study suggest that microbial decomposition of SOM under dryland production was reduced by the lack of human-induced wetting and drying cycles, and that irrigation management, more than any other treatment factor, was responsible for the greatest differences in SOM.

The maximum point in the SOM content under dryland production occurred between 9 and 10 years (i.e., 2010 and 2011,

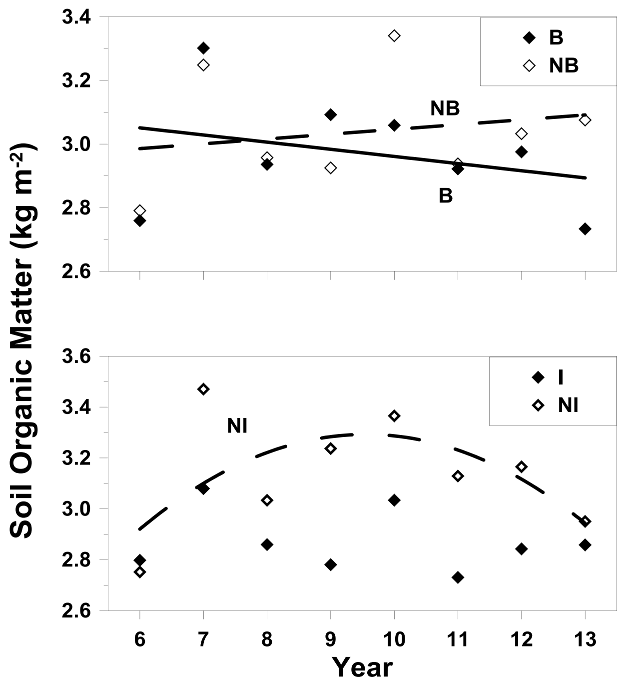

FIG. 3. Influence of burning (burn (B) and no-burn (NB)) and irrigation (irrigated (I) and nonirrigated (NI)) on soil organic matter content in the top 10 cm between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas. Soil organic matter content under the irrigated treatment did not differ across time and averaged 2.87 kg m^{-2}.

respectively; Fig. 3) after initial conversion and may have been influenced by changes in growing season weather patterns. During the Year 9 (i.e., 2010) growing season (i.e., June through October), total rainfall was 58% lower and monthly mean air temperature was 5% greater than the 30-year cumulative rainfall and mean monthly air temperature, respectively (Table 1; NOAA, 2002). Furthermore, soybean yield sharply decreased under dryland production between 6 and 11 years (i.e., 2007 and 2012, respectively) after initial conversion (Fig. 4), indicating a reduction in the additions of plant biomass under dryland production. The hot dry growing conditions occurring in 2010 likely also added to a reduction in crop biomass, microbial activity, and residue decomposition contribution to SOM.

Burning also significantly affected ($P = 0.015$) SOM content (Fig. 3). Averaged across N fertilization/residue level, tillage, and irrigation, SOM content decreased at a rate of −0.02 kg m^{-2} year^{-1} under residue burning but increased at a rate of 0.02 kg m^{-2} year^{-1} under nonburning (Fig. 3). Clearly, burning crop residues reduces the amount of plant material returned to the soil for potential microbial decomposition and eventual humification. This is consistent with a 4-year wheat-soybean study conducted on a Brooksville silty clay (Aquic Chromudert) in Mississippi that reported increased SOM content under no-burn NT treatment combinations compared with burn CT treatment combinations (Sanford, 1982). However, these results contrast the observations across the first 6 years after conversion to alternative management practices in which burning had no effect on SOM (Amuri et al., 2008) likely caused by insufficient time for measurable differences to appear.

As fractions of SOM, soil C and N contents were expected to behave like SOM content trends across time. Similar to SOM, the C content in the top 10 cm was affected ($P < 0.05$) by all field treatment factors evaluated. Also similar to SOM, the largest differences occurred between irrigated and nonirrigated treatments. Averaged across tillage, burning, and N fertilization/residue, soil C content increased at a rate of 0.16 kg m^{-2} year^{-1} ($P < 0.05$) under dryland production until approximately 9 years after initial conversion and then slightly decreased at a rate of 0.01 kg m^{-2} year^{-1} ($P < 0.05$) thereafter (Fig. 5). Conversely, C content decreased at a rate of 0.16 kg m^{-2} year^{-1} ($P < 0.05$) under irrigation until approximately 9 years after initial conversion and then slightly increased at a rate of 0.01 kg m^{-2} year^{-1} thereafter (Fig. 5). This result somewhat negates the hypothesis that C content would increase under irrigation.

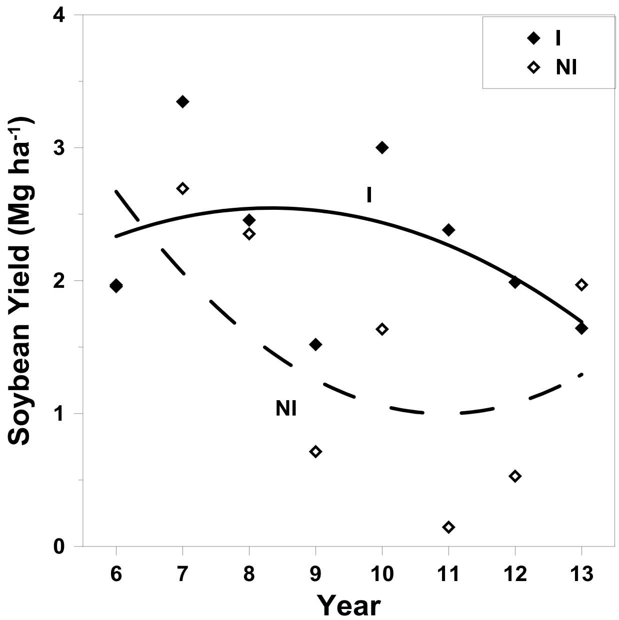

FIG. 4. Influence of irrigation (irrigated (I) and nonirrigated (NI)) on soybean yield between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas.

A substantial number (94%) of all soil C contents in the 8-year data set fell within a range of 1.0 to 1.6 kg C m^{-2} (Fig. 5). To put this range in context, 0.2 kg C m^{-2} extrapolated across 1 ha would equal 2,000 kg C. Considering that there were 34 million hectares of soybean planted in the United States in 2014 (USDA-NASS, 2015), the observed differences in C content may have a large-scale significance for the long-term sustainability of soybean production systems.

The results of this study are somewhat similar to those reported after 6 years following conversion to new management

TABLE 1. Summary of Monthly Total Rainfall and Average Air Temperature During the Soybean-Growing Season From Year 6 (2007) to Year 13 (2014) After Conversion to Alternative Management Practices at the Cotton Branch Experiment Station in East-Central Arkansas and the 30-Year Mean Monthly Rainfall and Air Temperature for the Region

Weather Variable/Month	Year 6 (2007)	Year 7 (2008)	Year 8 (2009)	Year 9 (2010)	Year 10 (2011)	Year 11 (2012)	Year 12 (2013)	Year 13 (2014)	30-Year Mean
Precipitation, cm									
June	9.3	3.9	8.9	3.3	6.4	2.0	1.9	24.8	11.2
July	15.3	5.4	21.8	6.7	12.3	6.5	7.1	6.5	9.7
August	2.3	15.2	6.4	1.6	8.6	3.1	4.8	11.9	6.9
September	7.6	6.6	12.3	2.1	5.6	12.3	11.1	3.4	8.0
October	10.3	7.3	32.1	5.4	5.7	11.5	6.8	11.5	9.6
Season total	44.8	38.4	81.5	19.1	38.6	35.4	31.7	58.1	45.4
Air temperature, °C									
June	27	27	27	29	28	26	26	26	25
July	26	28	26	28	29	28	26	25	27
August	29	26	26	29	28	27	26	27	26
September	24	23	23	25	21	24	24	23	23
October	19	17	16	18	16	16	17	18	17
Season mean	25	24.2	23.6	25.8	24.4	24.2	23.8	23.8	23.6

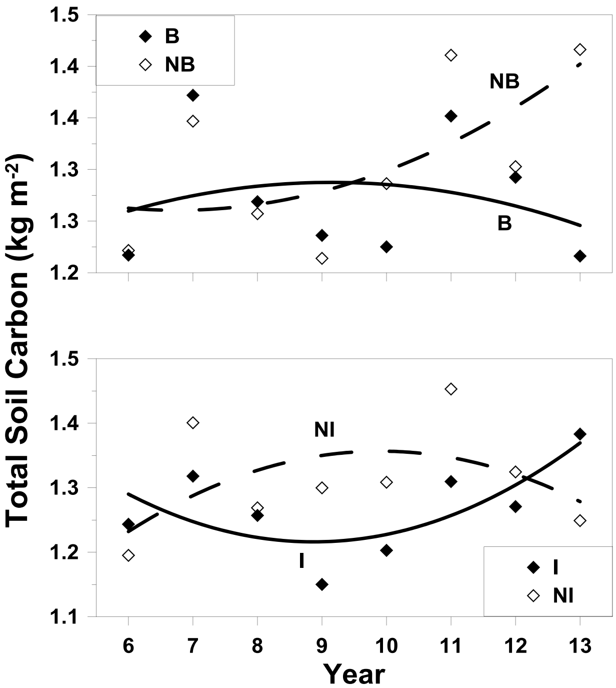

FIG. 5. Influence of burning (burn (B) and no-burn (NB)) and irrigation (irrigated (I) and nonirrigated (NI)) on total soil carbon content in the top 10 cm between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas.

practices in which soil C content increased at a greater rate under irrigation (0.11 kg C m^{-2} $year^{-1}$) than under dryland production (0.044 kg C ha^{-1} $year^{-1}$; Amuri et al., 2008). Likewise, Lal and Bruce (1999) suggested that soil C sequestration is strongly linked to irrigation practices, estimating that irrigated cropland sequesters between 50 and 150 kg ha^{-1} more C than nonirrigated cropland. In contrast, others have reported that greater soil C sequestration occurred under CT than NT (Frederick et al., 1998; Grandy et al., 2006).

The maximum points in soil C content trends under irrigated and nonirrigated soybean production (Fig. 5) occurred at approximately the same time as the maximum point in SOM trends under nonirrigated production (Fig. 3) and therefore may have been similarly influenced by changes in growing-season weather patterns. The increase in temperature and decrease in moisture may have caused a reduction in crop biomass, microbial activity, and residue decomposition, which may account for the shift from increasing to decreasing soil C content under dryland production between 9 and 10 years (i.e., 2010 and 2011, respectively) after initial conversion (Fig. 5). In contrast, growing conditions under irrigation were hot and moist, which may have increased microbial decomposition of crop residue and increased the amount of plant biomass converted into stabilized recalcitrant fractions of C.

Furthermore, although soybean yields under irrigation began to slightly decrease at approximately 9 years (i.e., 2010; $P < 0.001$; Fig. 4), yields continued to exceed those under dryland production throughout the entire study period, indicating that crop growth under dryland production was likely more affected by changes in growing season weather patterns. The annual additions of relatively large amounts of biomass from irrigated compared with dryland production may have influenced the quadratic increase ($P < 0.05$; Fig. 5) in soil C content under irrigation beginning at approximately 9 years after initial conversion.

Also similar to SOM, soil C content trends were affected ($P = 0.002$) by burning in a manner consistent with that hypothesized. Burning affected the quadratic ($P = 0.002$) but not the linear coefficient ($P > 0.05$). Under residue burning, soil C content began to decrease beginning approximately 9 years (i.e., 2010; $P < 0.05$) after initial conversion. In contrast, under the no-burn treatment, soil C content began to sharply increase beginning approximately 8 years (i.e., 2009; $P < 0.05$) after initial conversion. These results are similar to those reported after 6 years following conversion to alternative management practices, during which the rate soil C content increase was greater ($P = 0.008$) under nonburning than under burning (Amuri et al., 2008).

Similar to SOM and C, the trend in the C fraction of SOM in the top 10 cm was affected ($P < 0.05$) by all treatment factors evaluated. Averaged across tillage, burning, and N fertilization/residue level, the C fraction of SOM slightly decreased ($P < 0.05$) under both irrigated and dryland production until approximately 9 years after initial conversion, then increased ($P < 0.05$) thereafter at an approximately three times faster rate under irrigation than under dryland production. The greater increase in C fraction of SOM under irrigation (Fig. 6) was consistent with the increase in soil C content (Fig. 5) beginning approximately 9 years (i.e., 2010) after initial conversion.

Trends in soil C and/or SOM were often accompanied by similar trends in soil N content, which in the top 10 cm was affected solely by irrigation ($P < 0.001$) and unaffected ($P > 0.05$) by any other treatment factor. Averaged across tillage, burning, and N fertilization/residue level, soil N content increased at a rate of 0.03 kg m^{-2} $year^{-1}$ under dryland production until approximately 9 years after initial conversion and then slightly decreased at a rate of 0.002 kg m^{-2} $year^{-1}$ (Fig. 7). These results are in contrast to results reported after 6 years following conversion to alternative management practices, where the trend in soil N content

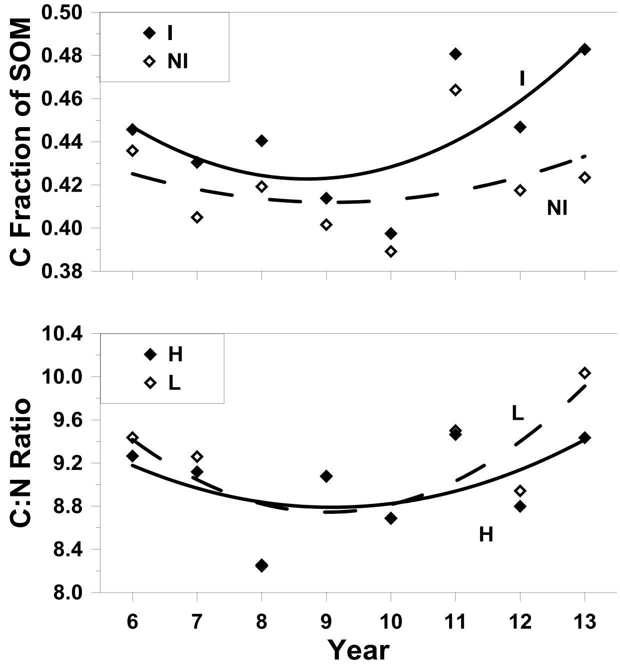

FIG. 6. Influence of N fertilization/residue level (high (H) and low (L)) and irrigation (irrigated (I) and nonirrigated (NI)) on soil C fraction of soil organic matter (SOM) and the soil C:N ratio in the top 10 cm between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas.

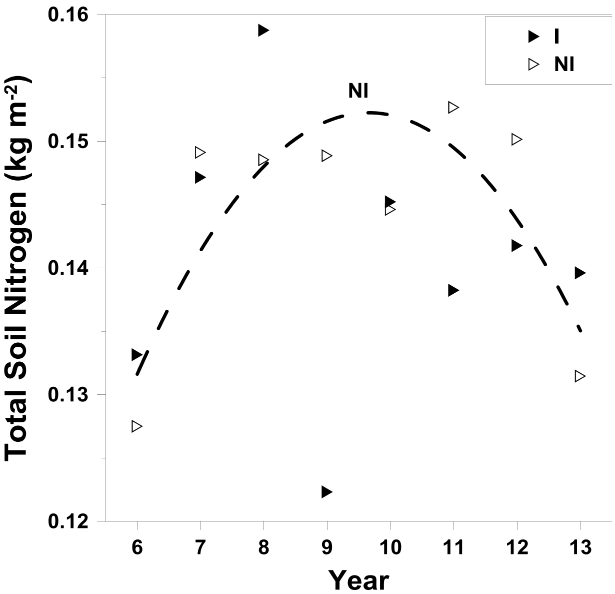

FIG. 7. Influence of irrigation (irrigated (I) and nonirrigated (NI)) on total soil nitrogen content in the top 10 cm between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas. Soil nitrogen content under the irrigated treatment did not differ across time and averaged 0.14 kg m^{-2}.

was unaffected by field treatments (Amuri et al., 2008). The maximum point approximately 9 years (i.e., 2010) after initial conversion (Fig. 7) roughly corresponds to the maximum points in SOM (Fig. 3) and soil C (Fig. 5) content and the C fraction of SOM (Fig. 6) and may have been similarly influenced by changes in growing season weather patterns. In contrast, there was no change in soil N content under irrigation ($P > 0.05$; Fig. 7), which averaged 0.14 kg m^{-2} during the 8-year period.

Evaluated independently, soil C and N provide useful information but evaluated together with the soil C:N ratio provide even more insight into the biogeochemical cycling of SOM and potentially other soil nutrients. The trend in soil C:N ratio in the top 10 cm was affected by all field treatments evaluated ($P < 0.05$). Averaged across tillage, burning, and irrigation, the soil C:N ratio decreased ($P < 0.05$) until approximately 9 years after initial conversion and then increased under both N fertilization/residue level treatments (Fig. 6). However, soil C:N ratio decreased at a greater rate before, and increased at a greater rate after 9 years after initial conversion (i.e., 2010), under the low versus the high N fertilization/residue level treatment (Fig. 6).

Although not supported directly by total soil N trends, one possible explanation for the N fertilization/residue level effect on soil C:N ratio is the temporary greater accumulation of inorganic soil N under the high N fertilization/residue level treatment. Soil under the high N fertilization/residue level treatment received 112 kg N ha^{-1} annually, whereas the low N fertilization/residue level treatment received no N for the entire 8-year study. Therefore, the slower increase in the C:N ratio under the high N fertilization/residue level treatment may have been influenced by the greater input of N fertilizer. This interpretation is consistent with a 50-year wheat-fallow cropping study on a silt-loam Typic Haploxeroll in Oregon, where unfertilized treatments had a greater soil C:N ratio than N-fertilized treatments in the top 30 cm (Rasmussen et al., 1980). It is also possible that soil microbes under the low-residue treatment lacked sufficient soil N to process SOM and C as rapidly as microbes under the high N fertilization/residue level treatment, especially given the relatively large C:N ratio of the wheat residue itself (C:N ≈ 55). Reduced microbial respiration efficiency may account for the greater accumulation of soil C compared with soil N under the low N fertilization/residue level treatment. In contrast to this study, after the first 6 years following conversion to new management, no significant trends in soil C:N ratio were reported (Amuri et al., 2008). Halvorson et al. (1999) similarly reported no significant effects on soil C and N dynamics as a result of high (134 kg N ha^{-1} $year^{-1}$) and low N rate treatments after 10 years of consistent management of a Weld silt loam (Aridic Argiustoll) in the Great Plains.

Soybean Yield

During the course of seven complete wheat-soybean cropping cycles (i.e., 2007–2014), after six complete consistent cropping cycles (i.e., 2001–2007), the trend in soybean yield was affected ($P < 0.05$) by only irrigation. Soybean yield increased ($P = 0.01$) under irrigation until approximately 9 years after initial conversion and then slightly decreased ($P < 0.001$) (Fig. 4). In contrast, soybean yield sharply decreased ($P < 0.001$) under dryland production between 6 and approximately 11 years after initial conversion and then slightly increased ($P = 0.003$) (Fig. 4). The water-stressed conditions during 9 and 11 years (i.e., 2010 and 2012, respectively; Table 1) after initial conversion may have caused a reduction in crop growth and yield, with the lowest soybean yields occurring between 10 and 11 years (i.e., 2011 and 2012, respectively) under dryland production (Fig. 4). Soybean yields are strongly affected by water availability and air temperature (Andresen et al., 2001), both of which are partially a function of climatic conditions and irrigation practices. In contrast to this study, soybean yields did not differ among field treatments in the first 6 years after conversion to alternative management practices (Amuri et al., 2008).

Soil Chemical Properties

The trends in soil EC and extractable soil Fe, S, and Na contents were unaffected by any of the field treatment factors evaluated. However, all treatment combinations increased or decreased at a statistically similar rate for each of these measured variables. Soil EC in the top 10 cm slightly decreased under all treatment combinations (data not shown). The slight decrease in soil EC was consistent with the linear decrease in extractable soil Na across all treatment combinations (−1.36 kg Na ha^{-1} $year^{-1}$; data not shown), indicating no substantial accumulation of salinity and soluble salts, even under irrigation. These results are similar to those reported during the first 6 years of consistent management, during which soil EC was unaffected by any field management practice and decreased significantly (Amuri et al., 2008). The lack of increasing salinity or EC, even under irrigation, may be partly explained by the low EC, Na, and chloride (Cl^-) concentrations in the irrigation water used (Amuri et al., 2008). Furthermore, there may be ample moisture to remove Na from the top 10 cm so that the damaging effects of soil dispersion, possible crusting, and destruction of structure at the soil surface are likely not to occur.

Similar to soil EC, the trends in extractable soil Fe and S in the top 10 cm were also unaffected ($P > 0.05$) by any field treatment evaluated but varied collectively in time ($P < 0.001$). Although the regression coefficient estimates indicated an initial increasing linear trend followed by a slight decreasing trend for both soil Fe and S (data not shown), the changes were inconsequential from an agricultural production standpoint. Sulfur is rarely a limiting nutrient in soybean production, and no Fe

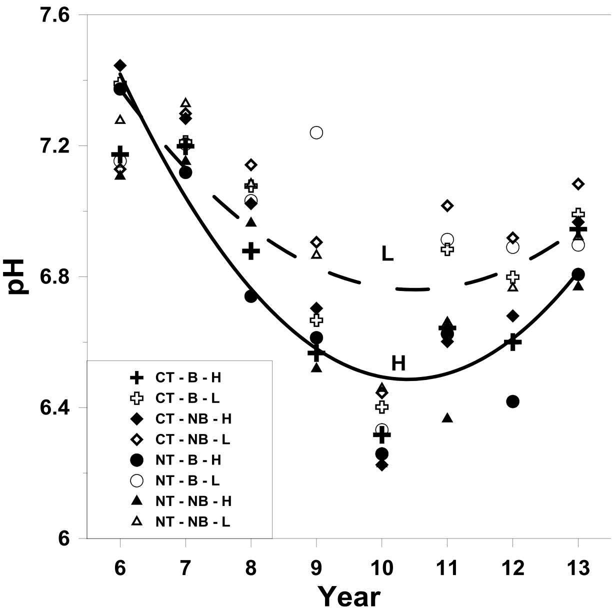

FIG. 8. Influence of N fertilization/residue level (high (H) and low (L)) on soil pH in the top 10 cm between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas.

deficiency for soybean has ever been diagnosed in Arkansas (Slaton et al., 2013).

In contrast to the lack of clear residue management practice effects on soil EC and extractable soil Fe, S, and Na, the trends in several measured soil properties, namely, soil pH and extractable soil P and Cu, exhibited large and obvious differences because of the imposition of a single treatment factor. The trend in soil pH in the top 10 cm was affected ($P < 0.05$) by all field treatments evaluated; however, the largest differences occurred between N fertilization/residue level treatments. Soil pH generally decreased under all treatment combinations until 10 years after conversion to alternative management and then generally slightly increased (Fig. 8). Specifically, averaged across tillage, burning, and irrigation, soil pH decreased at a greater rate under the high than under the low N fertilization/residue level treatment until 10 years after conversion and then increased at a slightly greater rate under the high than under the low N fertilization/residue level treatment (Fig. 8).

In contrast to this study, soil pH was unaffected by the N fertilization/residue level treatment, increased under irrigation, and did not change under dryland production during the first 6 years after conversion to new management (Amuri et al., 2008). A possible explanation for the shift from irrigation-driven changes during the first 6 years of new management to N fertilization/residue level–driven changes in soil pH between 6 and 13 years after conversion is that the lime applied at the initiation of the study in 2001 (Brye et al., 2006) may have progressively dissolved at different rates under irrigated and dryland management. If this occurred, then soil pH was likely most affected by irrigation treatments in earlier years and less affected in later years. All of the observed differences in soil pH trends occurred well above the threshold of 6.0, below which soybean yield reductions can be expected on silt-loam soils (Slaton et al., 2013). Therefore, although the differences in soil pH trends may be statistically significant, they are agronomically unimportant with regard to soybean production on silt-loam soils in eastern Arkansas.

Extractable soil P content trends were affected by irrigation ($P = 0.019$) and N fertilizer/residue level ($P < 0.001$) and was unaffected ($P > 0.05$) by tillage and burning. Similar to SOM, C, and N contents, the largest differences in soil P trends occurred between irrigation treatments. Averaged across tillage, burning, and N fertilizer/residue level, extractable soil P contents increased ($P < 0.001$) under dryland production until approximately 9 years after initial conversion, then decreased thereafter, whereas soil P content decreased quadratically across time under irrigation (Fig. 9). In contrast to this study, no differences were reported in extractable soil P content trends between irrigation treatments during the first 6 years after conversion to alternative management practices (Amuri et al., 2008). One possible explanation for why the trend in soil P content was most clearly affected by irrigation could be that changes in extractable soil P are associated with changes in SOM (Rhoton, 2000), in which the trend in SOM content in this study most clearly differed between irrigation treatments (Fig. 3). In addition, the trend in extractable soil P contents (Fig. 9) approximately mirrored the trend in SOM content under dryland production (Fig. 3).

The differences in extractable soil P content trends between irrigated and dryland management were both statistically and agronomically significant. Extractable soil P contents ranged between very low (<19.5 kg ha^{-1}) and medium (33.8–45.5 kg ha^{-1}) soil test P levels (Slaton et al., 2013). There is no evidence that P fertilization of soils with medium soil test P levels will produce a crop yield response, although fertilization may help maintain optimum P levels by replacing the portion of P removed by the harvested soybean grain (Slaton et al., 2013). The extractable soil P content trend under dryland management occurred mostly within the medium soil test P range (Fig. 9), indicating that P fertilization requirements for soybean on silt-loam soils in eastern Arkansas

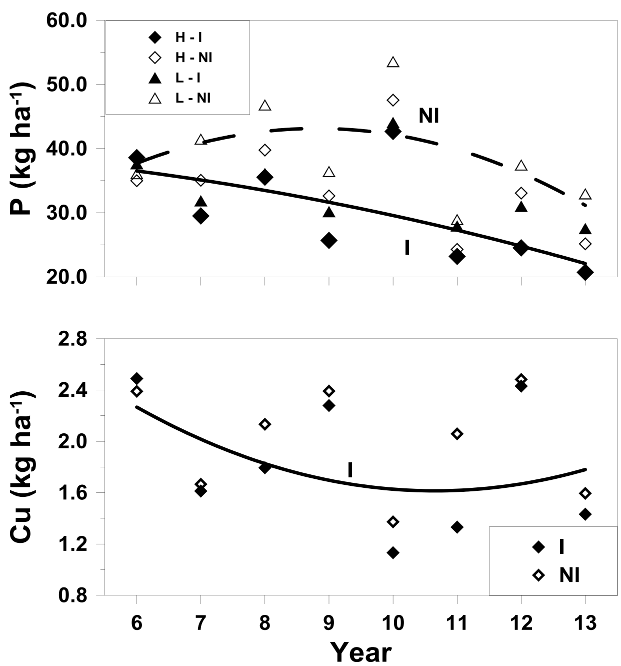

FIG. 9. Influence of N fertilization/residue level (high (H) and low (L)) and irrigation (irrigated (I) and nonirrigated (NI)) on extractable soil P and Cu contents between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas. Soil Cu content under the nonirrigated treatment did not differ across time and averaged 2.0 kg ha^{-1}.

may possibly be reduced under dryland management compared with irrigation management. These results suggest that irrigation treatment effects may impact the necessity, amount, and/or frequency of P fertilization. However, it is important to note that P deficiency in soybean is much less common than other potential nutrient deficiencies, such as K (Slaton et al., 2013).

Similar to P, the trend in extractable soil Cu content in the top 10 cm was affected by irrigation ($P = 0.009$) and was unaffected ($P > 0.05$) by tillage, burning, or N fertilization/residue level. Averaged across tillage, burning, and N fertilization/residue level, extractable soil Cu content decreased ($P < 0.001$) under irrigation until approximately 10 years after initial conversion, then slightly increased thereafter (Fig. 9), whereas there was no change in soil Cu content under dryland production ($P > 0.05$; Fig. 9), averaging 2.0 kg ha^{-1} during the 8-year period. In contrast to the results of this study, no differences were reported in extractable soil Cu content trends between irrigation treatments during the first 6 years after conversion to alternative management practices (Amuri et al., 2008). All extractable soil Cu contents (Fig. 9) were well above the threshold for low soil test Cu levels (i.e., <1 kg Cu ha^{-1}; Slaton et al., 2013).

Whereas trends in soil pH and extractable soil P and Cu were affected by only a single field treatment factor, extractable soil Ca, Mg, and Mn contents differed ($P < 0.05$) mainly among burn-irrigation treatment combinations. Averaged across tillage and N fertilization/residue level, extractable soil Ca increased ($P < 0.05$) under most nonburned nonirrigated treatment combinations until approximately 9 years after initial conversion, then decreased ($P < 0.05$), whereas extractable soil Ca contents decreased ($P < 0.05$) under nonburned irrigated production until approximately 10 years after initial conversion, then increased ($P < 0.05$) thereafter (Fig. 10). Although differences between extractable soil Ca content under the various treatment combinations may be of scientific interest, all measured extractable soil Ca exceeded plant growth requirements for most row crops in eastern Arkansas (Slaton et al., 2013).

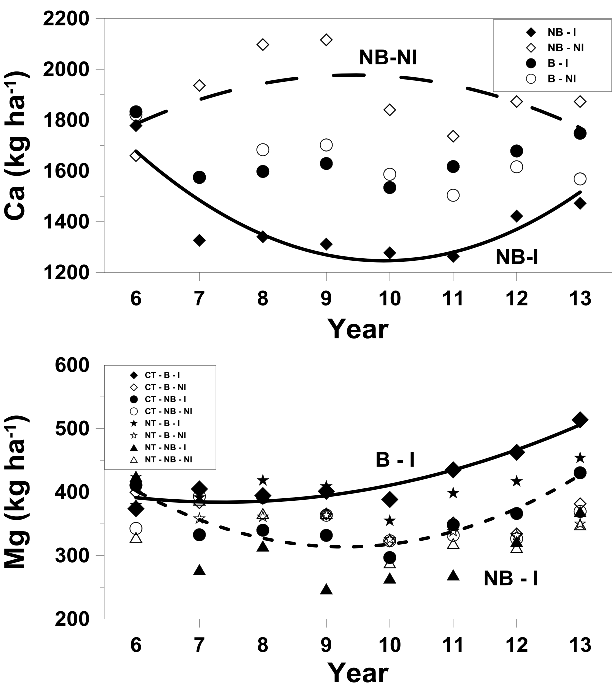

FIG. 10. Influence of burning (burn (B) and no-burn (NB)) and irrigation (irrigated (I) and nonirrigated (NI)) on extractable soil Ca and Mg contents in the top 10 cm between 6 and 13 years after initial conversion to alternative management practices in a wheat-soybean double-crop system in eastern Arkansas.

Similar to Ca, averaged across tillage and N fertilization/residue level, extractable soil Mg decreased slightly ($P < 0.05$) under burned-irrigated combinations until approximately 8 years after initial conversion, then increased thereafter (Fig. 10). Extractable soil Mg also decreased ($P < 0.001$) under nonburned-irrigated combinations, but at an approximate fourfold greater rate of decrease than under burned-irrigated management until roughly 8 years after initial conversion, then also increased ($P < 0.001$), but at an approximate threefold greater rate than under burned-irrigated management (Fig. 10). However, Mg deficiencies are rare for soybean production given that Mg is prevalent in eastern Arkansas groundwater (Slaton et al., 2013). Moreover, measured extractable soil Mg contents consistently occurred above the threshold for low soil test Mg levels (i.e., <45 kg ha^{-1}; Slaton et al., 2013). These results are in contrast to those reported after 6 years following conversion to new management, during which extractable soil Ca and Mg increased at a greater rate under irrigation compared with dryland production likely caused by the gradual dissolution of the initial application of lime in 2001 (Amuri et al., 2008).

Extractable soil Mn content differed ($P < 0.05$) among tillage-burn-irrigation treatment combinations. However, despite contributing to a significant higher-order interaction, tillage had no observable impact on extractable soil Mn. Thus, similar to Ca and Mg, differences in extractable soil Mn occurred among burn-irrigation treatment combinations. Averaged across tillage and N fertilization/residue level, extractable soil Mn contents sharply increased ($P < 0.05$) under the nonburned-irrigated treatment combinations until approximately 10 years after initial conversion, then decreased, whereas extractable soil Mn contents also increased ($P < 0.05$) in both burn treatments under dryland production, but at less than half the rate that occurred under the nonburned-irrigated combination, until approximately 9 years after initial conversion, then also decreased (data not shown). However, similar to soil Ca and Mg, measured extractable soil Mn contents were consistently well above the threshold for low soil test Mn levels (i.e., <13 kg ha^{-1}; Slaton et al., 2013). These results were also similar to those reported after 6 years following conversion to alternative residue management practices, during which extractable soil Mn increased under irrigation and did not change across time under dryland management.

Compared with other observed soil property trends in this study, the effects of residue management on extractable soil K and Zn were the most complex and involved all treatment factors. Extractable soil K contents generally decreased until approximately 11 years after initial conversion, then increased in all treatment combinations with the exception of in the NT-B-H-NI, CT-NB-H-NI, and NT-NB-L-NI treatment combinations, where extractable soil K contents did not vary across time (data not shown). Based on LSD among regression coefficient estimates, burning and N fertilization/residue level had less of an impact on soil K content than did tillage and irrigation. In contrast to the results of this study, extractable soil K contents decreased linearly under irrigation but increased under dryland management, indicating possible leaching of soil K because of the excess water provided by irrigation and/or increased plant uptake of soil K during the first 6 years after conversion to new management practices (Amuri et al., 2008).

Similar to K, extractable soil Zn content trends were complex compared with other measured soil properties, with differences between treatment combinations. Extractable soil Zn content was affected ($P < 0.05$) by all field treatments evaluated.

Extractable soil Zn increased ($P < 0.05$) across time in the NT-B-H-NI, NT-NB-L-I, NT-NB-L-NI, and CT-NB-H-I treatment combinations until approximately 10 years after conversion to new management, then decreased, whereas extractable soil Zn contents decreased ($P < 0.05$) in the NT-B-L-NI and CT-B-H-I treatment combinations until approximately 11 years after conversion to new management, then slightly increased (data not shown). In contrast to these results, extractable soil Zn contents increased under dryland management and did not change across time under irrigation during the first 6 years after conversion to alternative residue management practices (Amuri et al., 2008). Although extractable soil Zn content trends differed among various treatment combinations, no Zn deficiency has ever been observed or diagnosed in an Arkansas soybean crop (Slaton et al., 2013).

SUMMARY AND CONCLUSIONS

During the course of seven complete wheat-soybean cropping cycles (i.e., 2007–2014), after six complete cropping cycles (i.e., 2001–2007), all field treatments evaluated in this study affected trends in one or more measured soil properties and/or soybean yield. Irrigation management was responsible for the greatest differences in soybean yield, C fraction of SOM, and SOM, C, N, P, and Cu contents. Burning also significantly affected the SOM and C contents. Irrigation and burn treatment combinations were responsible for the greatest differences in soil Ca, Mg, and Mn contents. Nitrogen fertilization/residue level was responsible for the greatest differences in soil C:N ratio and pH. Soil EC and Fe, Na, and S contents were unaffected by any of the field treatments evaluated, but all varied significantly. Bulk density and K and Zn contents were affected by complex treatment interactions among tillage, burning, and irrigation.

Overall, it can be inferred from this study that irrigation management plays a critical role in the long-term trends in SOM, C, and N contents and other soil physical and chemical properties. Moreover, SOM, C, and N trends across time seem to be greatly influenced by growing season weather patterns, especially under dryland production. Many of the measured soil and plant property responses changed trajectory in the period of 9 to 11 years after conversion to new management, which indicates that roughly a decade is required before substantive changes to altered management practices are realized, at least in a wheat-soybean double-crop system in the Lower Mississippi River Valley.

Crop management that strikes a balance between increasing crop biomass and decreasing the rate of microbial turnover of SOM can maintain or increase SOM levels and thereby work toward long-term soil improvement and potential soil C sequestration. Despite many soil property magnitudes being agronomically nonsignificant in terms of Arkansas soybean production (i.e., soil pH and extractable soil Fe, S, Cu, Ca, Mg, and Zn), this study clearly demonstrated that alternative residue (i.e., NT and nonburning) and water (i.e., dryland production) management practices greatly impact near-surface soil property and soybean yield trends across time. This knowledge can be used to balance management decisions between short-term agricultural productivity and long-term ecological sustainability particularly in regions, like the Lower Mississippi River Delta, with a long history of intensive crop management.

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