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Near-Surface Soil Chemical Properties as Affected by Cover Crops Over Time in the Lower Mississippi River Valley

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Abstract

Typical row-crop agricultural practices can potentially be harmful to soil health and future sustainability. The use of cover crops (CC) as a mechanism to improve soil health on a wide scale remains underutilized. Soil health remains a major concern for the sustainability of agricultural productivity, therefore, research into CC implementation as a mean to preserve or improve soil health is warranted. The objective of this study was to evaluate the effects of CC on the soils in the eastern Arkansas portion of the Lower Mississippi River Valley (LMRV) over time for various chemical soil parameters, including pH, soil organic matter (SOM), soil elemental contents (*i.e.*, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu, and B), soil respiration, and a generalized soil health score index. Soil pH decreased over time under both CC and no-cover-crop (NCC) treatments, by −0.3 and −0.2, respectively. Soil OM decreased over time under NCC by −0.1%, but did not differ between CC treatments. Soil N availability decreased over time under NCC (−22.6 $kg \cdot ha^{-1}$), but did not change over time under CC. Soil respiration decreased over time under both CC and NCC, by −76.1 $mg \cdot L^{-1}$ and −77.3 $mg \cdot L^{-1}$, respectively, though there was no effect of CC treatment. The Haney soil health score index decreased under CC (−7.0) and NCC (−6.8) without an effect from CC treatment. Results of the study place emphasis on the temporal nature of soil health as influenced by cover crops and their potential to improve soil health.

Keywords

Arkansas, Cover Crops, Soil Properties, Soil Organic Matter, Soil Health Score

1. Introduction

The Delta region of eastern Arkansas and the Lower Mississippi River Valley (LMRV) in general, are important areas for cultivated agricultural production. General production practices, such as conventional tillage (CT) and irrigation, are cornerstones of typical row-crop agriculture. However, the over-turning and incorporation of crop residues into the soil, as is done in CT, leaves the soil surface bare, and potentially prone to erosion and associated nutrient runoff [1], and thus can decrease overall soil health. Additionally, the soil organic matter (SOM) present in a plowed field has the breakdown process facilitated from being exposed to much more intense aerobic conditions than normal, often resulting in C loss to the atmosphere. Tilled Arkansas soils exhibit between 41% to 63% of the soil C concentration as neighboring undisturbed prairies after 10 to 44 years of plowing [2]. Excess tillage, which reduces SOM and soil C contents, can facilitate the formation of surface soil crusts, reducing the amount of water that can infiltrate into the profile [3]. Along with tillage promoting SOM breakdown, soil water content, soil temperature, OM inputs, such as roots and crop residues, and microbial activity are the main factors promoting SOM accumulation.

An alternative to CT, conservation tillage can be used instead to provide minimal disturbance to the soil surface, minimizing susceptibility to erosion and nutrient runoff [4]. One such practice of conservation tillage is a no-tillage (NT) system. In 2017, the Soil Health Institute reported that only 16.8% of land area used in row-crop agriculture in Arkansas used a NT system [5], which leaves room to further implement NT systems across Arkansas. However, while NT has been shown to improve soil health on its own [4], soil health can continue to be enhanced through use of other complimentary conservation practices, such as the introduction of cover crops into a NT system, to improve soil health [4] [6].

Cover crops (CC) are plants, such as grasses, forbs, and/or legumes, that are generally grown between two cropping seasons, after a crop has been harvested and before the new crop is planted, in a field that would typically otherwise remain fallow. Typical CC in Arkansas are planted in fallowed fields during the fall to grow over the winter season, before being terminated in the spring to make way for the new cash crop [7]. Typically, a field is left fallow throughout the winter off-season after the cash crop harvest. Winter-fallow fields are susceptible to negative effects on the soil, such as erosion from both water and wind, soil crusting, and reduced aggregate stability, soil elemental concentrations, and infiltration rates [8]. However, CC can provide many benefits to overall soil health for both physical, hydraulic, and biological properties, which have been well-studied across a multitude of sites [9]-[11].

Cover crops have been recommended for implementation in Arkansas to improve soil health by means of providing cover to the soil surface, incorporating a living root biomass, as well as promoting biodiversity beyond that of a typical monoculture row-crop system [12]. However, the implementation of CC on a large scale in Arkansas remains unrealized, with only 4.2% of available cropland planted to CC as of 2017 [5], which increased to only 4.4% by 2022 [13], leaving room for a large expansion of CC use within Arkansas. Overall, the study and potential implementation of CC across the Arkansas portion of the LMRV might serve to better manage the several conservation problems facing the intensively cultivated, row-crop areas across eastern Arkansas.

The availability of soil nutrients often acts as a major constraint on plant growth, especially for certain macronutrients, such as nitrogen (N), phosphorus (P), and potassium (K). Soil N, P, and K, as well as other soil micronutrients [*i.e.*, iron (Fe), manganese (Mn), or copper (Cu), etc.], are vital for the proper function of biological processes within plants, contributing to protein creation, deoxyribonucleic acid replication, enzyme activation, and many other functions. While the availability of certain nutrients, such as P and/or K, is related to the inherent mineral makeup of a particular soil, the availability of other nutrients, such as N, could be bolstered by the presence of decomposing SOM-releasing nutrients back into the soil profile.

Runoff can negatively impact soil nutrient contents by washing certain nutrients away, such as N and/or P, from the soil surface from rainfall and/or irrigation [14]. One way to mitigate runoff volume, and thereby better retain soil nutrients, is through the use of CC systems. The effects of CC on physical soil properties, such as decreasing bulk density to promote a greater proportion of macropores [15] and increasing aggregate stability to prevent the formation of soil crusts [16], can thereby increase overall infiltration rates [16] [17], all of which can contribute to an overall reduction in runoff. Additionally, the physical presence of CC, particularly the root systems of the plants and the organic matter that roots contribute, serve to enhance the soil's hydraulic conductivity, through greater soil aggregation, further mitigating runoff, and thereby the loss of nutrients [18].

To facilitate growth, plants, such as cash crops, must take up nutrients, such as N, P, and K, through the root network, such that the nutrients can be available for the multitude of functions vital in the process of plant health, growth, and productivity. The harvest of crops has been shown to have a strong impact on the reduction of available soil nutrients, especially with regards to density and mass of the crops planted [19]. However, through the use of CC, soil nutrients are not only kept within the soil profile through a reduction in runoff, but the CC themselves can further contribute to reducing nutrient loss by their own absorption of nutrients to keep nutrients in the field from where the nutrients were extracted, though only if the CC are allowed to remain on and in the soil, rather than harvested. Therefore, many soil nutrients remain safely stored away from the effects of surface erosion, as nutrients are kept in place [20], though there remains the possibility of limiting nutrient availability for the next crop without swift nutrient mineralization.

One analytical method used to determine soil chemical properties and their contribution to soil health is the Haney test, particularly the Haney soil health score, which can be used to quantify several different properties, one of which is a soil-CO_2-C-burst method. Soil CO_2-C is a relevant soil metric because soil CO_2-

C can be increased by the presence of a CC treatment, reaching up to 40% greater CO_2 emissions than a NCC treatment, due to effects such as increased root respiration and enhanced soil microbial activity [21]. The amount of CO_2-C produced by a soil can be examined as a surrogate for microbial activity through the respiration of soil microbes recorded in a 24-hour burst. The Haney soil health test also utilizes a Haney, Haney, Hossner, Arnold (H3A) extractant and reports a soil health score as an index of soil respiration and water-extractable organic C and N to represent an overall soil health indicator or score [22]. Another soil test of interest is the Nitrogen-Soil Test for Rice (N-STaR; *Oryza sativa*) [23]. Unlike many other soil-N tests, the N-STaR test can measure a combination of simple organic N compounds as well as soil ammonium-N (NH_4-N) to determine a composite N concentration, as well as the amount of organic N likely to be mineralized within the growing season [23].

Given that site-specific soil conditions can alter the extent and rapidity of potential CC impacts [10] [11], it is important to document CC effects across different regions. Arkansas is already suffering from aquifer depletion [24] and is suffering losses of 2.2 to 11.2 Mg of soil per hectare each year from erosion in some places [12], with the effects of erosion expected to get worse as climate change continues [25]. Cover crops may provide a sustainable alternative management practice option for at least some parts of Arkansas that can contribute to both conserving limited water resources and maintaining and/or improving overall soil health. The objective of this study was to evaluate the temporal effects of CC on select near-surface soil chemical properties (*i.e.*, pH, Mehlich-3-extractable soil elemental contents, Haney soil health parameters, and N-STaR soil N availability) among several Major Land Resource Areas (MLRA) in the eastern Arkansas portion of the LMRV.

Due to the increase in crop residues on and in the soil profile, it was hypothesized that there would be an increase in SOM under CC over time compared to NCC. With an increase in SOM that can undergo decomposition, it was hypothesized there would be a decrease in pH over time under CC compared to NCC. Similarly, with the increase in organic material available for breakdown by soil microbes, it was hypothesized that there would be an increase in soil respiration over time under CC compared to NCC. Additionally, due to CC's ability to minimize erosion, it was hypothesized that the soils under CC would experience less elemental loss over time under NCC. With the increased presence of plant residue available in the soil, it was hypothesized that the overall plant-available N content would increase over time under CC compared to NCC. Lastly, from the overall implementation of CC, it was hypothesized that the soil health score index would increase over time under CC compared to NCC.

2. Materials and Methods

2.1. Site Descriptions

Over the course of three growing seasons, from Fall 2018 through Summer 2021, soil samples were collected from 13 sites in the Lower Mississippi River Valley (LMRV) with paired CC and NCC systems. Samples were collected from a total of 39 fields across 14 sites and 11 counties between Arkansas and Tennessee (**Figure 1**).

The first site was in MLRA 131A, near West Memphis, AR, and consisted of two fields, one on a silt loam with CC and the other on a silty clay loam with NCC treatment. Soybean (*Glycine max*) was the established cash crop in both fields, with cereal rye (*Secale cereale*) as the CC. The NCC field was managed as continual conventional tillage, while the CC field was conventionally tilled for only the first growing season (2018) before converting to a NT system.

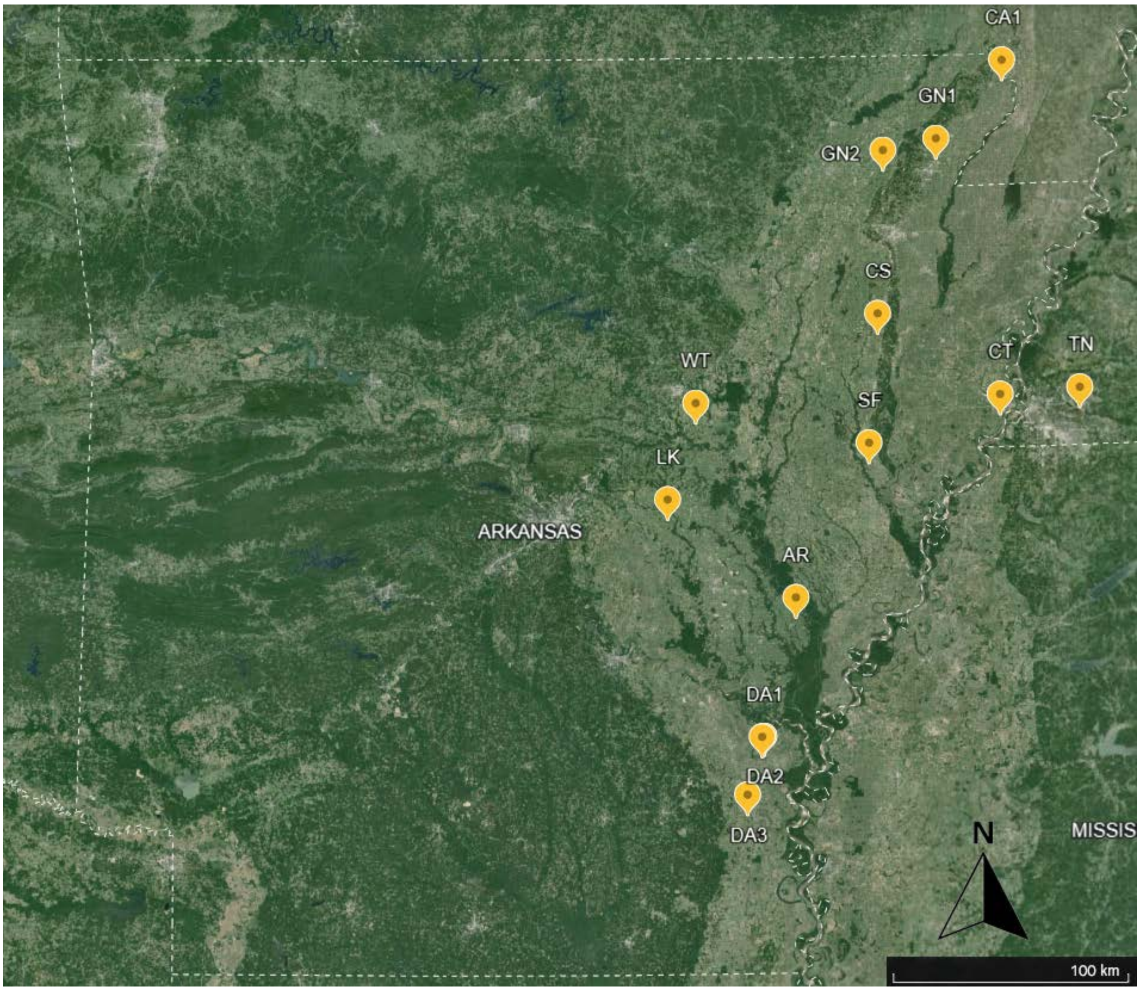

Figure 1. Spatial distribution of specific research sites within the Lower Mississippi River Valley region of eastern Arkansas and western Tennessee (adapted from Google Earth).

The second site was in MLRA 131A, near Paragould, AR, and consisted of three fields on silt-loam soils. One of the fields was a NCC treatment, with an established soybean cash crop and conventional tillage management system. The other two fields, which were adjacent to one another, also had a soybean cash crop, as well as a mix of cereal rye, black-seeded oats (*Avena sativa*), and crimson clover

(*Trifolium incarnatum*) as the CC established in 2018 and managed under NT.

The third site, also near Paragould, AR in MLRA 131A, was split between two fields on silt-loam soils. The two bedded fields each had a cash crop of levee rice (*Oryza sativa*) before the start of the study (2017), followed by soybean in the first growing season (2018) and row rice from thereafter. The field that received the NCC treatment was conventionally tilled in the first growing season (2018), followed by a minimal tillage system, where furrows were lightly cleaned either yearly or every other year, while the field that received the CC treatment was managed under NT after a combination of wheat (*Triticum aestivum*), oat (*Avena sativa*), clover (*Trifolium* spp.), and cereal rye were established in 2019.

The fourth site was in MLRA 131A, near Piggott, AR, across four bedded fields on silt-loam soils, where two fields had CC and two fields had NCC. Corn (*Zea mays*) was grown in the NCC fields with conventional tillage before 2018, then was converted to cotton (*Gossypium hirsutum*) under a minimal tillage system from 2018 and thereafter. The CC fields were under NT management before 2018, but once cereal rye was established in 2018, the fields were converted to a system of minimum tillage, which involved light cleaning of furrows.

The fifth and sixth sites were in MLRA 131B at Stevens Farms, near Dumas, AR, and included four bedded fields total on silt-loam soils. The fields at the fifth site both had cotton throughout the duration of the study, where one NCC field was under minimum tillage, incorporating light cleaning of furrows, and the other field had cereal rye as the CC that was initially established in 2016 and managed under NT. Fields at the sixth site were prepared similar to those of the fifth site.

The seventh site was in MLRA 131B, near McGehee, AR, with two CC fields and two NCC fields on silt-loam soils. The fields under NCC were conventionally tilled with soybean prior to 2018, subsequently being converted to cotton for 2018 and thereafter. The fields under CC were under NT cotton and cereal rye CC.

The eighth site was in MLRA 131D, near Searcy, AR, across two bedded fields on silt-loam soils. Soybeans were established across both fields before 2018, followed by corn during 2018, then back to soybean thereafter. The CC field did not have a cover crop established until 2019 when cereal rye was established under NT, while the NCC field was conventionally tilled for the study's duration.

The ninth site was in MLRA 131D, near DeWitt, AR, with two fields on silt-loam soils. Corn was grown in both fields throughout the study, with the field under CC having a combination of black-seeded oats, crimson clover, and Florida broadleaf mustard (*Brassica juncea*) established in 2019.

The tenth site was in MLRA 131D, near Carlisle, AR, and consisted of two bedded fields on silt-loam soils. Soybean was grown in both fields before 2018 and was converted to corn during 2018 before returning to soybean in 2019 and thereafter. The field under NCC was conventionally tilled through 2019, then converted to a minimal-tillage system thereafter, including light cleaning of furrows. The CC field had cereal rye established in 2019 with minimum tillage, which had previously been under conventional tillage before the CC was established.

The eleventh site was in MLRA 134, near Forrest City, AR, across two CC fields, one on a silt-loam and one on a silt soil, and two NCC fields on silt-loam soils. No-tillage cotton was grown on all four fields for the duration of the study. Two fields had a cereal rye CC established in 2018 that persisted throughout the study.

The twelfth site was in MLRA 134, near Cherry Valley, AR, with four fields on silt-loam soils. Across all fields, corn was grown prior to 2018 then converted to soybean in 2018, then back to corn in 2019 and thereafter, with each crop managed under NT. The two CC fields had a mix of cereal rye, black-seeded oats, crimson clover, and Austrian winter peas (*Pisum sativum subsp. Arvense*), originally established in 2015, throughout the duration of the study.

The thirteenth site was in MLRA 134 at the Shelby County Agricultural Extension Center, near Germantown, TN, with two fields on silt-loam soils. Cotton was grown in both fields throughout the duration of the study, with the NCC field conventionally tilled. The CC field was managed under NT, with a cereal rye CC established in 2019.

Soil particle-size analyses were conducted using a using a modified 12-hour hydrometer method [26]. Particle-size distributions and soil surface textural class for each site followed procedures and results described in Fanning [27].

The selection, establishment, and management of cover crops across all sites generally followed the recommendations for best management practices by the University of Arkansas, Cooperative Extension Service [7]. All cover crops were established after a summer cash-crop growing season before being terminated in the spring, approximately 2 to 4 weeks before the next cash-crop growing season. Fields that underwent CT typically consisted of one or several passes with a furrow runner or chain-disk plow to a depth of 7 to 15 cm every year. Fields that underwent CT were typically cropped without CC, while fields with CC typically were managed under NT. However, for a variety of reasons, not all measurements or planned sample collections were conducted in a consistent manner across all sites [27].

2.2. Soil Sample Collection, Processing, and Analyses

A series of 25 to 30 soil cores were collected from the tops of raised beds when applicable throughout the treatment area from each site to a depth of 15 cm with a 2.5 cm-diameter push probe. Cores were combined into a single composite sample. In treatment fields larger than 8 ha, the area was split into two separate composite samples to ensure no single composite sample comprised more than 8 ha. Composite samples were then oven-dried at 70˚C for 48 hours before being manually sieved through a 2-mm mesh to remove any coarse fragments or roots for soil physical and chemical analyses. Samples were initially collected in the fall of 2019 and winter of 2019-2020, except for the samples from the Shelby County Agricultural Extension Center, which were collected in the spring of 2020. Final sample collection took place in the fall of 2021, except for the samples collected from the Shelby County Agricultural Extension Center, which were collected in spring 2021.

Soil organic matter concentration was measured by weight-loss-on-ignition, where soil was combusted in a muffle furnace for 2 hr at 360˚C [28]. Soil pH was determined potentiometrically using an electrode in a 1:2 (mass/volume) soil-to-water mixture [28]. Extractable soil elemental concentrations (*i.e.*, P, K, Na, Mg, Ca, S, B, Zn, Cu, Mn, and Fe) were determined from soil extracted with Mehlich-3 extractant solution in a 1:10 (mass/volume) soil-to-solution mixture and analyzed by inductively coupled, argon-plasma, atomic emissions spectrometry (ICAP-AES; CIROS CCD model; Spectro Analytical Instruments, MA) [29]. Measured soil concentrations were converted to contents ($kg \cdot ha^{-1}$) using a thickness-weighted average of the measured bulk densities to represent the 0- to 15-cm depth interval. The thickness-weighted average was calculated by averaging the 0 - 10 and 10 - 20 cm depth bulk density replicates for each site. From there, the 0 - 10 cm depth average was multiplied by 0.67 and the 10 - 20 cm depth average was multiplied by 0.33 to represent two-thirds and one-third of the 15-cm, soil-sample-collection thickness, respectively, after which the two products were summed to determine the 15-cm thickness-weighted average bulk density that was used to calculate soil elemental contents.

The N-STaR approach is a soil-based test that can quantify the amount of N that will become available to the crop, rather than relying on traditional measurements of purely inorganic NH_4-N or nitrate-(NO_3-N) N [23]. Instead, the N-STaR test assesses the combination of ammonium and organic N in the form of readily mineralizable N. In addition to NH_4-N, N-STaR measures amino acids and amino sugars present in plant and/or soil microorganism tissues. To quantify the amount of organic N that will become available after mineralization, N-STaR uses direct steam distillation of a soil sample from the 0- to 15-cm depth interval, with intense heat and a large concentration of sodium hydroxide (NaOH). The resulting amount of N released after the distillation process is used as an index of N availability.

The Haney soil health index [22] offers a comprehensive assessment of overall soil health, as well as an evaluation of specific soil health parameters, such as soil respiration. After combining the results of multiple soil property analyses, including levels of water-extractable soil carbon and nitrogen and soil respiration, a soil health score is calculated, which serves as a quick indicator of the current soil health compared with other soils with different management systems, where scores range from 0 to 50 [22] and larger scores generally indicate a healthier soil. The soil respiration, or soil CO_2-C concentration, is calculated over a 24-hr period following drying and rewetting. Similar to procedures used in Chu *et al.* [30], soil respiration was determined using the Solvita CO_2 burst test (Woods End Laboratories, Mt. Vernon, ME) [31], where 40 g of air-dried soil were placed in a 50-mL perforated beaker with a microfiber filter paper at the bottom of the beaker. The beaker and the Solvita gel paddle were placed in a 200-mL beaker filled with 12 mL of water, which were incubated for 24 hours at 25˚C after being sealed. The total CO_2 respired during the 24-hour period for each sample was determined via a Solvita digital-color reader (DCR 700, Woods End Laboratories, Mt. Vernon, ME) [31].

2.3. Statistical Analyses

A one-factor analysis of variance (ANOVA) was conducted with the PROC GLIMMIX procedure in SAS (version 9.4, SAS Institute, Inc., Cary, NC) to evaluate the effect of cover crop treatment (*i.e.*, CC and NCC) on the change in soil pH, SOM and extractable soil elemental concentrations, and measured N-STaR (*i.e.*, total N content) and Haney (*i.e.*, soil health score and soil respiration) parameters over time. A normal distribution was used to evaluate all measured or calculated parameters because all response variables statistically analyzed represented changes over time, for which the values could be positive (*i.e.*, an increase) or negative (*i.e.*, a decrease). Means were separated by least significant difference at $p < 0.05$. Furthermore, to evaluate if the magnitude of change over time differed from zero, a t-test was conducted, with significance evaluated at $p < 0.05$.

3. Results and Discussion

Throughout the study, the data collected served as an evaluation of multiple different row-crop agricultural production sites within the LMRV, specifically selected to result in large variability for the parameters of interest across sites and to evaluate treatment effects that may hold across a large and variable spatial distribution. Thus, any statistically significant change in a particular soil property would represent a real trend in the use of CC, rather than due to any random variation. While individual practices such as fertilization rates or irrigation use were not specifically accounted for in the current study, following recent procedures [32], the current study is justified in the approach that, due to the vast spatial distribution of the current study, any significant differences imparted by CC and/or changes over time will represent, substantial differences/changes that persisted across large variability.

3.1. Soil pH and Soil Organic Matter

As an indicator of nutrient availability, the change in soil pH in the top 15 cm over time was unaffected by CC treatment ($p > 0.05$; **Table 1**). However, soil pH decreased over time in both the CC (−0.3) and NCC (−0.2) treatments (**Table 1**). Additionally, as an indicator of soil productivity, the change in percent SOM in the top 15 cm over time was unaffected by CC treatment ($p > 0.05$; **Table 1**). However, the SOM decreased over time under NCC (−0.1%) compared to CC, which did not change over time (**Table 1**).

Similar to the current study, a recent study on silt-loam and loam soils in the LMRV with cotton, soybean, and corn cash crops and cereal rye, canola (*Brassica napus*), hairy vetch (*Vicia villosa*), turnip (*Brassica rapa subsp. rapa*), and switchgrass (*Panicum virgatum*) CCs, while having not examined a change over time, reported that there was no difference in soil pH in the top 10 cm of soil between CC and NCC treatments [32]. Similarly, a six-year study on a silt-loam soil in the LMRV under a wheat-soybean double-crop system reported no effect on soil pH within the top 10 cm of soil due to crop residue level (*i.e.*, low and high) or tillage treatment (*i.e.*, CT and NT) [33]. However, in contrast to results of Amuri *et al.* [33], a continuation study at the same site under the same treatment conditions reveled that, when averaged across tillage, burning, and irrigation, soil pH decreased in the top 10 cm of soil under the high-N-fertilization/residue combination by a greater rate than under low-N-fertilization/residue level treatment for the first 10 years after treatment initiation [34]. Furthermore, past the first 10 years, Norman *et al.* [34] then reported that soil pH levels began to increase, by slightly greater rates under the high-N-fertilization/residue than under low-N-fertilization/residue-level treatment.

Table 1. Analysis of variance and means summary of treatment (*i.e.*, cover and no cover) effects on the change in soil chemical properties in the top 15 cm over time across various sites in the Lower Mississippi River Valley.

Property	p	n†	Cover	No cover
pH	0.24	31	−0.3*††	−0.2*
SOM§ (%)	0.84	31	−0.09	−0.10*
Phosphorus ($kg \cdot ha^{-1}$)	0.86	25	−7.3	−5.8
Calcium ($kg \cdot ha^{-1}$)	0.47	25	−122	−11.0
Potassium ($kg \cdot ha^{-1}$)	0.17	25	−34.5*	−9.4
Magnesium ($kg \cdot ha^{-1}$)	0.21	25	−42.2*	−7.6
Sulfur ($kg \cdot ha^{-1}$)	0.74	25	6.8*	5.9*
Sodium ($kg \cdot ha^{-1}$)	0.81	25	8.7*	9.5*
Manganese ($kg \cdot ha^{-1}$)	0.43	25	18.5	30.9*
Iron ($kg \cdot ha^{-1}$)	0.42	25	1.2	28.8
Zinc ($kg \cdot ha^{-1}$)	0.99	25	−0.003	−0.008
Copper ($kg \cdot ha^{-1}$)	0.52	25	0.5*	0.6*
Boron ($kg \cdot ha^{-1}$)	0.20	25	−0.3*	−0.2*
N-STaR§ nitrogen ($kg \cdot ha^{-1}$)	0.04	24	11.4 a‡	−22.6* b
CO_2-C§ ($mg \cdot L^{-1}$)	0.93	31	−76.1*	−77.3*
Soil health score	0.87	31	−7.0*	−6.8*

†n, number of observations; §SOM, soil organic matter; N-STaR, nitrogen soil test for rice; CO_2-C, carbon dioxide-carbon respiration; *Indicates value is significantly different from a change of 0 ($p < 0.05$); ††Positive mean values represent an increase, while negative mean values represent a decrease over time; ‡Different lowercase letters in the same row indicate values are significantly different at $p < 0.05$.

With a decrease in pH across both NCC and CC systems, soil pH was likely influenced by some other environmental factor, such as precipitation [35], which can lead to the leaching of alkaline cations from the soil, leading to acidification. Furthermore, soil pH can fluctuate on an annual basis due to varying levels of soil moisture, by up to as much as 0.5 units [36]. Additionally, the implementation of certain fertilizers, particularly NH_4-N fertilizers, has an acidifying effect from nitrification [37] [38]. Without an effect of CC treatment, compounding environmental or management practices, such as rainfall or fertilizer addition, likely resulted in the decrease in soil pH over time.

Similar to the current study, another recent short-term study reported that SOM content in the top 10 cm of soil was unaffected by CC treatment, though the study did not specifically examine a change over time [32]. Additionally, a three-year study on silt-loam, silty-clay-loam, silty-clay, and very-fine-sandy-loam soils in the Delta region of Mississippi with corn and soybean cash crops and black oats, cereal rye, hairy vetch, Austrian winter peas, tillage radish (*Raphanus sativus*), winter triticale (*Triticosecale rimpoui*), and Balansa clover (*Trifolium michelianum*) CCs reported SOM levels in the top 15 cm were unaffected by CC compared to NCC treatment [39]. However, within the eastern Arkansas portion of the LMRV, long-term study of a wheat-soybean, double-crop system on a silt loam showed that, after 14 years, there was a 7% greater SOM concentration in the top 10 cm of the soil in a NT/high-residue compared to a CT/low-residue treatment combination (24.2 and 22.6 kg·ha^{-1}, respectively) [40].

Tillage has been shown to decrease SOM content in the top 10 cm in eastern Arkansas [2]. Therefore, the NCC, which was primarily managed under CT, compared to CC system likely experienced a decrease in SOM over time because of CT increasing the oxygen content and microbial activity of the soil, thus stimulating decomposition. In addition to tillage affecting SOM by altering the inputs of crop and CC residue, CC biomass growth and potential OM inputs can be affected by local weather, particularly rainfall and temperature. Adequate rainfall will promote greater CC biomass than moisture-limited conditions. Similarly, warming soil will promote CC growth and productivity, unless a late freeze occurs. However, considering CCs will eventually be terminated prior to cash-crop planting, the potential negative effects of local weather conditions are generally inconsequential.

3.2. Soil Nutrients

As a measure of soil fertility, the change in Mehlich-3 extractable soil elemental contents in the top 15 cm of soil over time was unaffected by CC treatment for all elements measured ($p > 0.05$; **Table 1**). However, both K and Mg contents decreased over time, by −34.5 and −42.2 kg·ha^{-1}, respectively, under CC than under NCC, which did not change over time (**Table 1**). Additionally, the S and Na contents increased over time under both CC (by 6.8 and 8.7 kg·ha^{-1}, respectively) and NCC (by 5.9 and 9.5 kg·ha^{-1}, respectively; **Table 1**). Manganese contents did not change over time under CC, but increased over time under NCC by 30.9 kg·ha^{-1} (**Table 1**). Copper contents increased under both CC (by 0.5 kg·ha^{-1}) and NCC (by 0.6 kg·ha^{-1}), while boron contents decreased under both CC and NCC (by −0.3 and −0.2 kg·ha^{-1}, respectively; **Table 1**).

Overall, the effects of CC on soil elements are known to be widely variable [41]. Similar to the current study, [32], while not having examined specifically for a change over time, reported that all measured soil elements in the top 10 cm (*i.e.*, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, and Cu), with the exception of Na, were unaffected by CC treatment. However, in a one-year study in the LMRV on silt-loam, clay, and fine-sandy-loam soils under a corn cash crop and cereal rye CC, soil P and K were variable in the top 15 cm, with a decline in soil-test P at one site and a decline in soil-test K at the other, due to CCs [42]. In a different study spanning periods of 11 and 14 years, soil Fe and S in the top 10 cm changed over time, but without a CC effect, while the trends of other nutrients, such as K or P, were affected by fertilizer-N/residue-level combinations, with soil K initially decreasing over the first 11 years after treatment initiation, though irrigation was noted as likely having a larger role than residue treatments [34].

The vast majority of soil K is stored within minerals in a form unavailable to plants and must first be released via weathering or decomposition [43], instead requiring fertilizer-K additions for quicker plant availability. Previous studies have shown that minimal-tillage or NT systems, such as was used in the CC treatment in the current study, can result in nutrient stratification, such as with soil K, with large concentrations towards the soil surface [44] [45], due to the lack of incorporation/mixing from tillage of soil-surface K additions. When combined with common landscape characteristics of the eastern Arkansas Delta region that are known to be susceptible to runoff [46], surface-applied K is likely to be lost in runoff in a NT or minimal-tillage system compared to CT, likely leading to the measured soil-K reduction over time. However, the extent to which K runoff is likely also depends on the cation exchange capacity of the soil, where a large cation exchange capacity with low amounts of other basic cations could act to hold K within the soil profile to result in minimal runoff-K losses.

Soluble soil Mg is easily lost via leaching [47], where spatiotemporal variations in soil properties and environmental processes, such as soil moisture or precipitation, could then result in a reduction of plant-available soil Mg over time, regardless of CC presence. For soil S, many soils in Arkansas that use flood- or furrow-irrigation draw from groundwater that contains large amounts of alkaline ions, such as Ca, which has led to an increase in soils above a pH of 6.5, consequently requiring to the use of amendments, such as elemental S, to acidify soils towards an optimal pH range for nutrient availability [48]. The use of S-containing acidifying amendments could likely be responsible for the increase in soil S over time without an impact from CC, while also further serving as a potential explanation for the previously mentioned decrease in pH regardless of CC treatment. For soil Na, the groundwater used for irrigation in the Mississippi River Valley alluvial aquifer contains several ions in solution, one of which is Na [49]. The use of groundwater for irrigation with elevated levels of dissolved Na could potentially lead to an accumulation of excess soil Na following evaporation, leading to the measured increase in soil Na over time in the current study.

Significant reduction in SOM, to which ionic Mn can bind and become unavailable, as well as a decrease in pH resulting in increased Mn availability [50] are likely why Mn availability increased over time under NCC conditions. The availability of Cu to plants in soil solution shares an inverse relationship with soil pH [51]. The measured soil-Cu increase over time across CC treatments likely resulted from the previously observed reduction in pH across CC treatments. Plant-available B is primarily introduced to the soil by the breakdown of organic matter into boric acid, a neutral molecule, that is unable to adhere to charged soil surfaces, and is therefore easily leached from the soil profile [52]. The already low soil-B level could allow slight alterations, such as a decrease in microbial activity, to further decrease soil B over time across CC treatments.

3.3. Nitrogen-Soil Test for Rice and Haney Soil Health Score

As a comprehensive indicator of N availability, the change in N-STaR-N content in the top 15 cm over time was affected by treatment ($p = 0.04$), with N-STaR N decreasing over time under NCC (by −22.6 $kg \cdot ha^{-1}$), while not changing over time under CC (**Table 1**).

Similar to the current study, Lebeau *et al.* [32] reported that there was no effect of CC on total N in the top 10 cm, though the study did not specifically evaluate for a change over time. Additionally, a 14-year study reported there to be no impact of residue level on total N in the top 10 cm [34]. Furthermore, a two-year study in Illinois on silt-loam soil under corn and soybean cash crops and cereal rye and hairy vetch CCs reported that there was no effect of CC implementation on total N in the top 30 cm [53].

The presence of CCs compared to a fallow field is able to decrease runoff potential by acting as a physical barrier to the kinetic forces of precipitation that would otherwise wash away soluble soil N [14]. Additionally, CCs such as cereal rye, the primary CC implemented within the current study [27], are able to take up residual nutrients left from the primary growing season and store the nutrients within plant biomass, further preventing their loss via runoff [7]. With the presence of CC on and in the soil after the winter season, the crop residues are available for decomposition, releasing N, and other nutrients, back into the soil profile for future plant uptake. The cycling of nutrients, in addition to the anchoring effect the physical presence CC can provide, likely resulted in the lack of reduction in soil N under CC compared to NCC, which lacked a runoff barrier, resulting in a decrease in soil N over time under NCC. Additionally, while several studies have shown CC implementation to not impact total soil N [32] [34] [53], these studies did not use the N-STaR evaluation method, which can account for N stored in organic matter that can mineralize and become available for plant uptake [7]. The difference in soil-nutrient evaluation could account for the lack of reduction in soil N over time under CC, whereby N that may have otherwise been lost as runoff is kept within the system by the CC.

As a measure of SOM decomposition and microbial activity, the change in CO_2-C over time in the top 15 cm was unaffected by CC treatment ($p > 0.05$), but decreased over time in both CC (by −76.1 mg·L^{-1}) and NCC (by −77.3 mg·L^{-1}) treatments (**Table 1**). Additionally, as an overall index of soil health, the Haney soil health score was unaffected by CC treatment ($p > 0.05$), though there was a decrease over time in both the CC (by −7.0) and NCC (by −6.8) treatments (**Table 1**).

Similar to the current study, another study evaluating the Haney soil health score on a silt-loam soil from 0-15 cm in Tennessee across a three-year period with corn and soybean cash crops and cereal rye, wheat, hairy vetch, crimson clover, oats, daikon radish (*Raphanus sativus*), and purple top turnip (*Brassica campestris*) CCs reported no effect on soil respiration from any CC treatment [30]. However, another study using the Haney soil health score evaluation in California on a clay loam over a 15-year period utilizing cotton, tomato (*Solanum lycopersicum*), sorghum (*Sorghum bicolor*), and garbanzo bean (*Cicer arietinum*) cash crops and Juan triticale (*Triticosecale* Wittm.), rye, vetch, pea (*Pisum sativum*), faba bean (*Vicia faba*), radish, and Phacelia (*Phacelia tanacetifoli*) CCs reported an increase in soil respiration within the top 30 cm under CC treatment [54]. Like the current study, Chu *et al.* [30] reported no difference in the soil health score across CC treatments, attributing soil biology, rather than CC implementation, to be the primary driver of the soil health score.

Soil respiration, based on the Haney soil respiration 24-hour-burst method, is the release of CO_2 from the breakdown of SOM by soil microbes. With soil respiration decreasing over time without an effect from CC treatment, it is likely that there was some interruption to soil microbial activity. Due to the nature of the burst test analyzing processed and dried soil [22], various factors during the analysis process itself could have contributed to the measured reduction in soil respiration. If, in the rewetting process, the soil is over-saturated, there can be a substantially reduced CO_2 response [55]. Additionally, the preparation process of grinding soil samples can also interfere with soil cohesion, resulting in a potential over-saturation during the burst test [55]. Furthermore, added SOM and C could have been translocated deeper into the soil profile, accumulating at a depth that would not be accounted for in the 15-cm sample depth, especially if soil samples were collected from a raised bed, as was done in the current study.

The Haney soil health score is an index that serves as a summary of the soil respiration, as well as measured water-extractable organic C and N [22]. While the latter two parameters of water-extractable organic C and N were not directly measured, approximately 95% of the variation in the index can be attributed to the CO_2-burst measurement [56], thus it stands to reason that any trend exhibited by soil respiration would be the most indicative of the trend of the soil health score. From the measurements of the current study, there was a reduction in soil respiration over time, as well as either the reduction or lack of change in SOM over time. The lack of significant increases in either microbial activity or SOM likely resulted in the decreased soil health score regardless of CC treatment.

3.4. Reasons for Lack of Significant Results

The effects of CC on soil chemical properties, particularly soil elemental contents, are known to be variable [41]. For the current study, an overall trend of the soil chemical property results across nearly all measured parameters was that, while some soil chemical properties might have changed significantly over time, almost every parameter, aside from N-STaR N, was unaffected by CC treatment. The lack of significant differences, particularly for soil elemental contents, could be due to crop nutrient removal [57] or to field management differences, such as the rate or timing of fertilizer application, across individual sites included in the dataset evaluated in the current study. Furthermore, the fields that were bedded effectively had two layers of topsoil stacked on top of one another. For the bedded fields, the collected soil samples may have over-represented the upper layer of the natural soil, which may not be representative of any changes occurring deeper in the soil across all parameters.

Additionally, the time period between which soil samples were collected for analysis was short, spanning only one to two years, depending on the parameter. Many studies have demonstrated that soil chemical properties have experienced no effect from CC use within the short time frame of only a few years [32] [33] [39] [53]. However, further studies have shown that CC implementation can eventually have an effect on soil chemical properties given enough time [34] [40]. Considering the short-term nature of the current study, in which the soil chemical property changes were evaluated over a period of ≤2 years, any effects that may eventually result from CC use likely have just not had enough time to manifest yet, highlighting time as a key factor in understanding the impacts that CCs can impart upon soil chemical properties.

3.5. Implications

The aim of the current study was to evaluate the differences imparted on select near-surface soil chemical properties as a result of CC implementation, thus, only the impact of CC treatment was evaluated. This study did not account for individual field management practices, such as timing and rates of fertilization, rates of irrigation, or other similar factors. However, similar to Lebeau *et al.* [32], the current study used a suite of sites across a large spatial area in order to create large variability. Consequently, any significant differences were considered to be persistent impacts as a result of CC implementation, rather than due to some other random or unknown soil factor(s).

A determination of the specific improvements that CC can impart upon soil chemical properties will allow for a more well-informed decision-making process for producers to utilize CC to improve Arkansas soil health in the LMRV. Arkansas production systems, in particular, can suffer from alkalinity and salinity, primarily introduced by well water used for irrigation [58]. However, close care to identifying water sources is needed, as reservoir water is notably less alkaline than well water in Arkansas, which can impact soil acidification with the application of N-based fertilizers. Additionally, Arkansas well water can contain large levels of sodium, which can act to disperse soil and can interfere with both water and nutrient access for the plant. Understanding how CC can impact such properties in the eastern Arkansas portion of the LMRV could potentially help to reduce potential negative ramifications associated with using groundwater for irrigation.

While most measured soil properties were unaffected by CC implementation, instead changing over time as the result of some other external factor, given the results of previous studies [34] [40] [59], many of the soil properties would be expected to further change over time and deviate from NCC after an initial implementation period to the point where CC would have a significant impact. Reaching the point at which measured soil chemical properties would demonstrate a significant difference due to CC would necessitate longer-term studies throughout the LMRV, with multiple sampling times throughout a year across a term of several years to decades in order to discern true effects on overall near-surface soil health in the eastern Arkansas portion of the LMRV. The comparison of a particular agroecosystem's suite of chemical property changes over extended time periods (*i.e.*, >3 years), as well as across a variety of sites in the LMRV, will provide a more well-rounded analysis of the varying impacts of CC on near-surface chemical properties.

Due to a variety of stressors, such as increasing global population growth and global air temperatures, the strain on agricultural production is only expected to grow, accounting for the need to combat the risk to agriculture from severe weather events, as well as the need to increase overall outputs [60] [61]. If the maintenance of soil health is ignored, extreme weather events and conditions from climate change, when in conjunction with increasing agricultural production, are known to result in an overall reduction in production instead [1] [16] [62]. Research into the long-term effects on soil health that CC can impart can help producers make comprehensive judgements in maintaining and eventually improving the soil health when under duress from global stressors [63] [64]. As Arkansas is an important region in the US for the production of several crops [65], the benefits to conservation that can be made in the management of row crops will not only improve conditions for local producers, but also the entire LMRV region.

4. Conclusions

While the general benefits to soils from CC implementation are well-known, the effects when incorporated into Arkansas row-crop production systems are less understood. This study contributed to filling the research gap by examining a wide variety of various near-surface soil properties related to soil health across a wide range of sites within the LMRV, primarily in eastern Arkansas. The hypothesis that pH would decrease over time under CC compared to NCC was not supported, as soil pH decreased across both treatments, but without an effect from CC. The hypothesis that SOM would increase under CC compared to NCC was also not supported, as SOM did not change under CC, and, while SOM decreased over time under NCC, the presence of CC or lack thereof had no effect on the temporal SOM change.

Similarly, the hypothesis that there would be less soil-element loss with CC compared to NCC was also not supported. Soil K and Mg decreased over time only under CC, soil Mn increased over time only under NCC, soil S, Na, and Cu increased over time under both CC treatments, soil B decreased over time under both CC treatments, while soil P, Ca, Fe, and Zn did not change over time under either CC treatment. Furthermore, none of the aforementioned soil elements that changed over time were affected as a result of CC presence or lack thereof. The hypothesis that soil N would increase over time under CC compared to NCC was partially supported, where soil N under CC did not increase over time, but soil N under NCC decreased over time.

Results did not support the hypothesis that there would be an increase in soil respiration under CC, instead, both CC and NCC experienced reduced soil respiration over time without an effect by CC. Lastly, the hypothesis that the Haney soil health score index would increase over time under CC was not supported, instead, CC and NCC experienced a decrease in the soil health score, without an effect from CC implementation. Overall, results of this study provided greater insight into the necessity of further research on potential effects of CC in the eastern Arkansas portion of the LMRV, as well as calling attention to the importance of having a sufficient time pass since implementing CC to significantly impact soil chemical properties related to soil health.

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Conflicts of Interest

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

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