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Cover Crop Effects on Near-Surface Soil Aggregate Stability in the Southern Mississippi Valley Loess (MLRA 134)

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Abstract

Intensive agricultural cultivation within major land resource area (MLRA) 134, the Southern Mississippi Valley Loess, has led to soil erosion, soil compaction, and the overall destabilization of near-surface soil aggregates. The use of cover crops during the agricultural off-season has been shown to help alleviate soil compaction and provide stabilizing effects against soil erosion, which are particularly important as the silty soils of MLRA 134 have a large erosion potential. This study evaluated the effects of cover crop and no-cover crop treatment on silt-loam soils within MLRA 134. Treatments were implemented during Fall 2018 and Fall 2019 and consisted of a range of cover crop species, including cereal rye (*Secale cereale*), black oats (*Avena strigose*), crimson clover (*Trifolium incarnatum*), and Austrian winter pea (*Pisum sativum subsp. Arvense*). Soil samples from the top 10 cm were collected to evaluate soil bulk density, pH, soil texture, water-stable aggregates (WSA), total WSA, soil organic matter (SOM), and Mehlich-3 extractable nutrients. Soil texture, pH, and SOM and Mehlich-3 extractable nutrient (i.e., Mg, Na, Ca) concentrations and contents were unaffected ($P > 0.05$) by treatment. Total WSA was unaffected ($P > 0.05$) by cover crop treatment or soil depth (i.e., 0-5 and 5-10 cm). Soil bulk density was greater ($P < 0.05$) without cover crops (1.27 g cm^{-3}) than with cover crops (1.24 g cm^{-3}). Water-stable aggregate concentration was unaffected ($P > 0.05$) by cover crop treatment or soil depth but was 21.47 times greater ($P < 0.05$) in the 0-0.25-mm (1.138 g g^{-1}) than in the > 4-mm (0.053 g g^{-1}) size class. Study results indicate that cover crops can have short-term, positive effects on soil properties, but a long-term commitment to cover crops is likely necessary for the full realization of potential benefits.

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Introduction and Literature Review

The use of cover crops is an ancient technology, but reliable research has only existed on the topic for less than a century. Research has revealed the intricacies of how cover crops affect soil and water quality and erosion potential. These complexities are why further research is warranted, especially as soil conservation is becoming more popular, and, in some instances, required for certain governmental, cost-sharing, assistance programs, like the Conservation Reserve Program (CRP). The Conservation Reserve targets highly erodible lands that are environmentally sensitive (i.e., sloped with loamy textures) and pays landowners a yearly rental fee to remove fields from cultivated agricultural production and to plant species that improve environmental and soil quality over a contracted period of 10 to 15 years (USDA-FSA, 2021).

Soil and Water Quality

Soil quality is a complex topic combining the chemical, physical, and biological properties that affect how soil interacts with the surrounding environment. Studying soil is difficult as identifiable changes take several years and some recommendations suggest a study period of 10 years before substantive changes are manifested (Abdollahi & Munkholm, 2014).

One common metric often associated with assessing soil quality is quantifying aggregate stability by measurement of water-stable aggregates via a wet-sieving procedure. The wet-sieving method subjects soil aggregates to mechanical disturbance, as oscillations in a column of water atop a nest of sieves of varied sizes, which are commonly 4-, 2-, 1-, 0.5-, and 0.25-mm in size (Smith et al., 2014). The wet-sieving process separates each soil sample into different aggregate-size classes based on the sieve they are retained on top of as the mechanical disturbance occurs. Some aggregates can withstand disturbance and are retained on the larger sieves, while another mass fraction of soil is broken down into smaller aggregate sizes or disintegrates altogether and passes through the smallest sieve sizes.

A soil aggregate is a grouping of sediment and organic matter particles bound together stronger than adjacent particles (NRCS, 2008). The formation and stability of soil aggregates is a complex process that is affected by several factors. Soil aggregates form from physical, chemical, and biological processes and are divided into micro (< 250 µm) and macroaggregates (> 250 µm). Soil aggregate stability is significantly affected by soil organic matter (SOM), texture, cation exchange capacity, and pH. Soil organic matter is the most critical component in aggregate formation (Pihlap et al., 2021), where SOM acts as a binding agent for soil particles and allows for the formation of microaggregates. Microaggregates form from the attachment of clay particles to organic molecules, along with cationic binding agents, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), silicon (Si^{4+}), and aluminum (Al^{3+}) (Bronick & Lal, 2005). The effect of cations on soil structure is disrupted when high concentration of ions, such as Na^{+}, separate clay particles from binding agents resulting is expansion and dispersion (Pearson, 2003). This is because the sodium ions compete for space on clay platelets but do not flocculate clay particles as Ca^{2+} and Mg^{2+} are able to do. This repeated expansion and dispersion results in a reduction in infiltration, hydraulic conductivity, and increase in the amount of time the surface is sealed by a crust. Macroaggregates can also form around decomposing particulate organic matter. As the organic matter decomposes, microaggregates begin to form within and eventually the macroaggregate breaks apart into smaller, more stable microaggregates (Bronick & Lal, 2005). Aggregate formation processes require that SOM exist within the profile and is easily disrupted by mechanical tillage. With the increase in available oxygen during soil disturbance (i.e., tillage), SOM decomposes at a faster rate, thus decreasing the amount of SOM facilitating the aggregation of soil particles (La Scala et al., 2008).

Soil aggregates are also heavily influenced by soil texture. As SOM acts as a binding agent, so does the clay in the soil, which also depends on the type of clay present (Bronick & Lal, 2005). Clays with a large potential for swelling may result in swelling-induced disaggregation, but the significance is greatly reduced in soils with low clay contents (Attou et al., 1998). The interactions of clay particles are important to aggregate stability in more than one way. Along with clay particles, negatively charged organic matter interacts with available cations that bridge soil aggregates together, increasing the strength of the soil aggregate (Tisdall & Oades, 1982). The creation of aggregate bridges creates a clay "fabric" that aids in the soil's resistance against slaking and other erosion forces (Attou et al., 1998).

The dispersion of clay, along with the exchange of cations and microbial decomposition of SOM, are all also affected by soil pH. At an alkaline pH, clay particles tend towards flocculation and the formation of larger soil aggregates. An increase in soil pH also often supports an increase in microbial activity, promoting plant growth and increased SOM concentrations (Bronick & Lal, 2005). These factors are critical to consider, as a soil's physical, chemical, and biological properties can substantially impact the effectiveness of agricultural systems that use cover crops.

Cover cropping often increases soil fertility and plant-available nutrient concentrations when consistently practiced over time (Smith et al., 2014). Cover crops increase SOM when terminated and tilled under as a green manure. Soil organic matter is also increased by a harvested cover crop, such as winter wheat (*Triticum aestivum*), as plant roots decompose after the marketable product is collected (Bronick & Lal, 2005). Soil nitrogen (N) is increased when the terminated cover crop is a N-fixing legume, such hairy vetch (*Vicia villosa*), and berseem clover (*Trifolium alexandrinum).* The use of hairy vetch and/or berseem clover can increase soil N by 90 to 200 kg ha^{-1} and 75 to 200 kg ha^{-1}, respectively, when tilled under as a green manure (Curell, 2015). Prior to establishing the primary crop, such as soybeans (*Glycine max)* or dent corn (*Zea mays indenata)*, the cover crop is often terminated to facilitate planting. Termination of a crop refers to the point in time when the cover crop is purposefully killed off to prepare for the production crop to be planted. During termination, the cover crop can either be harvested, tilled under as a green manure, rolled, or chemically terminated. If used as a green manure, the termination process can be an essential part of recovering degraded soils as nutrients and organic matter are removed during production agriculture.

Not only is soil quality enhanced by cover crops, but water quality can be protected as well. Cover crops aid in reducing sediment, nutrient, and pesticide transport into surrounding water bodies by reducing runoff (Dabney et al., 2001). Cover crops can reduce soil erosion in runoff by providing canopy cover and protection against raindrop splash. Roots function as anchors keeping the soil in place during overland flow and increase the resilience of soil aggregates. Nutrient and pesticide runoff can be similarly reduced as sediment-adsorbed nutrients and pesticide molecules are kept in place during wind and water erosion events. Researchers measured an 86% decrease in the amount of nitrate (NO_3^-) and a 53% decrease in phosphate (PO_4^-) in edge-of-field runoff samples over two years with cover crops at one site, but changes observed at the paired site were non-significant over time (Aryal et al., 2018). Measurements showed that pollutant concentrations (i.e., nitrate, nitrite, phosphate, and sediment) were lower during the production crop growing season (May through October) than during the rest of the year. The sites assessed by Aryal et al. (2018), in eastern Arkansas near

Caraway and Manila, consisted of comparable size and soil properties, having textures such as fine sandy loam, very fine sandy loam, or silt loam. Treated fields were fertilized with phosphorus (P) and potassium (K) and followed by either an oat (*Avena sativus L.)* or winter wheat cover crop. The duration of the cover crop was two winter seasons that was then followed by a third year of baseline study. The increase in soil stability from the cover crops had many benefits, the most immediate being the decrease of soil erosion.

Soil Erosion

The most notable benefit of using cover crops to increase soil aggregate stability is the measurable reduction in wind and water erosion. Cover crops lead to a decrease in the amount of wind and water erosion, as cover crops shield the soil surface from raindrop impact and anchor the soil with their roots. The use of barley (*Hordeum vulgare*) has been shown to increase the strength of soil aggregates by 29% in the field and by 53% in the greenhouse based on drop testing because of root anchoring (Loades, 2010). Researchers identified that approximately 20% of the land in the United States under production requires some form of soil restoration and recommend the use of cover crops as a part of restoration actions (Langdale et al., 2014). Langdale et al. (2014) evaluated the effectiveness of different cover crops preventing water and wind erosion based on a region's dominant soil order. Results showed that meadow and prairie species prevented erosion better in regions with Mollisols, while other cover crops, like forage radish (*Raphanus sativus var. oleiformis*), prevented erosion better on Ultisols and Alfisols (Langdale et al., 2014).

The time at which cover crops are terminated is also important to consider. When a crop is terminated too early, potential benefits are diminished, as the soil is no longer protected against erosion because of a lack of cover. The concern of a sudden lack of surface cover is minimized when producers terminate their crop and leave the terminated residue on the soil surface to provide cover (Balkcom et al., 2015). If a cover crop is terminated too late, then the yield of the production crop may be harmed due to a lack of soil moisture and poor seed-to-soil contact (Balkcom et al., 2015). Often, the success of a crop depends on the availability of water, and, if a cover crop has decreased the amount of plant available water, then the need for irrigation increases. In xeric areas with little rain and limited irrigation, drier years that had a cover crop resulted in lower cotton (*Gossypium hirsutum*) yields compared to fields that did not use a cover crop (Raper et al., 2000). In areas that cannot afford to lose soil moisture to cover crops, researchers suggest the use of residues from the production crop to shield the soil surface from evaporative moisture losses (Unger & Vigil, 1998). However, using residues results in a reduction in benefits, such as the inability of residues from harvested crops to fix atmospheric N as a leguminous cover crop could have.

Erosion is a natural process but is exacerbated using tillage for agricultural purposes. Tillage aims to create a medium in which crops grow easily and emergence is more successful than would be in the unprepared soil. However, tillage disturbs soil aggregates in topsoil and increases the potential for water or wind to detach soil particles during erosional events. With the use of the Agricultural Production System sIMulator (APSIM), researchers predicted that, in a 45-year period, the use of cereal rye (*Secale cereale*) cover crops in American midwestern corn (*Zea mays*)-soybean rotations could decrease soil erosion by 11 to 29% and nitrous oxide emissions by 34% (Basche et al., 2016). Basche et al. (2016) also concluded that, as soil erosion decreased, the depletion of soil carbon (C) was slowed by approximately 3% over 45 years when a cereal rye cover crop was simulated compared to similar testing sites that were left bare without a cover crop. The decrease in soil erosion potential is attributed to the shallow and widespread portion of the root system provided by grass cover crops, as more of the soil matrix becomes entangled by roots. Cereal rye also provides a dense, aboveground cover of > 95% that protects the soil surface against the raindrop impacts (Roberts et al., 2018). Annual weed density and biomass was also shown to decrease by > 90% in the following production season compared to similar fields that were left bare when cereal rye was used as a winter cover crop (Werle et al., 2017). Werle et al. (2017) also demonstrated that, not only is cereal rye a favorable cover crop, but cereal rye shows promising results as part of an alternative weed control system. The use of cover crops with large taproots has been shown to naturally perform biological tillage, which alleviates the negatives of reduced tillage systems, like compaction and poor infiltration (Chen & Weil, 2010). The natural mixing of the soil by biological tillage allows reduced forms of mechanical tillage to be more successful by alleviating soil compaction, which, in turn, should make the use of such methods more popular among producers.

The use of cover crops has several tangible benefits, such as increasing soil aggregate stability, N fixation, decreasing erosion potentials, and sequestering carbon (Abdollahi & Munkholm, 2014). The use of cover crops varies in popularity across the United States because of the advent of easier ways to produce large yields with chemical fertilizers and pesticides. However, these easier ways are not always sustainable. Thus, research on the use of cover crops and reduced tillage systems is necessary to ensure soil conservation efforts into the future in locations that have inherent characteristics that are prone to soil erosion, such as major land resource area (MLRA 134) of eastern Arkansas.

MLRA 134 - Southern Mississippi Valley Loess

Throughout a portion of eastern Arkansas is MLRA 134, known as the Southern Mississippi Valley Loess. The Southern Mississippi Valley Loess occupies a total of ~ 68,686 km^2 (26,520 mi^2) across seven states and, of the total area, ~ 7,555 km^2 (2,917 mi^2), or 11%, resides in Arkansas (NRCS, 2006). The Southern Mississippi Valley Loess stretches from Piggott, AR in the northeast to Helena, AR to the south to the Mississippi River east of Memphis, TN.

Geologically, MLRA 134 is covered by a loess mantle, ranging from 0.3 to 1.2 m thick, that was wind-deposited as fluvial surface sediments, which were blown east from the west between 130,000 and 10,000 years ago, and is underlain by marine sediments. The deposition of loess resulted in soils that are deep, range from well to somewhat poorly drained, and are loamy textured. The topography of the region is gently sloping and increases in elevation from the Mississippi River towards Crowley's Ridge. Deep gullies are still visibly present in areas surrounding Crowley's Ridge, as evidence of past, severe water erosion of the highly erodible, loess-covered landscape of MLRA 134.

The most common use of freshwater in MLRA 134 is irrigation from groundwater sources, which pose their own problem as water withdrawn from the alluvial aquifer under eastern Arkansas has an extensive list of problems (NRCS, 2006). The large amount of groundwater and surface water coincides with the land use of MLRA 134, as 36% is cropland, where much of the area is used for rice (*Oryza sativa*), cotton, and soybean, all of which require irrigation for maximum production. According to NRCS (2006), within MLRA 134, water erosion, maintenance of SOM, and the management of soil moisture are major concerns.

Among the concerns for the Southern Mississippi Valley Loess, water-induced soil erosion is a focus of the Natural Resources Conservation Service (NRCS). Water erosion occurs naturally in all environments across the world in tolerable amounts and is known as geologic erosion. Water erosion has become a problem because of the accelerated pace at which the erosion occurs due to more intensive land use, particularly the extent of cultivated agriculture. Cultivated agricultural land is often left with exposed soil surfaces for parts of the year, leaving the soil vulnerable to the impact of raindrop splash and overland flow. To reduce the amount of soil being eroded, the implementation of best management practices (BMPs), like cover crops, are used worldwide and are being evaluated in MLRA 134 in Arkansas.

Cover crops are crops that are planted in the off-seasons and fallow periods in annual cropping seasons to provide canopy cover on soils that would otherwise be bare (Meerkerk, 2008). The use of cover crops has been shown to not only provide direct cover for the soil against raindrop impact and detachment, but also improve soil aggregate stability, soil N content, and soil hydrology (De Baets et al., 2011). Cover crops were once common on farms in Arkansas, but, with the advent of chemical compounds, such as commercial inorganic fertilizers, to achieve large crop yields and decrease the risk of economic loss, the use of cover crops significantly decreased (Humphreys, 2016). Because of the problems associated with the accelerated soil erosion by water and wind, cover cropping remains an easy and effective way for producers to decrease the effects soil erosion may have on their land.

Justification

The loss of soil is a loss of a finite resource that requires a research-supported approach from both scientists and producers that includes the use of cover cropping to improve soil physical properties to withstand erosive influences (i.e., wind and water). As of 2016, there were no recommendations for the use of cover crops available to producers and, as a result, Arkansas producers were less likely to utilize cover crops (Humphreys, 2016). Since 2016, recommendations for cover crops have been provided by several agencies, the most widespread being from the University of Arkansas, Division of Agriculture. In 2018, the first statewide cover crop fact sheet for row-crop producers was published, citing many of the benefits of cover crops, such as improved soil structure, reduced runoff, and increased soil N (Roberts et al., 2018). Due to the recent encouragement of cover crop use, applied research is warranted to identify the impacts of cover crops on aggregate stability in highly erodible, loess soils in MLRA 134.

It is critical to the conservation of soil resources that ways to improve aggregate stability are further researched and refined so that recommendations continue to improve, and BMP adoption and implementation become more widespread. Along with recommendations, the development of statewide BMPs to strengthen aggregate stability are necessary so that Arkansas producers have the information they need to improve their cropland. Without the use of BMPs, like cover cropping, soil aggregate stability will continue to degrade between production seasons and, as a result, soil erosion will continue and may even accelerate (Humphreys, 2016).

Objective and Hypotheses

The objective of this field study was to evaluate the effects of cover crops on soil aggregate stability and associated near-surface soil properties in the Southern Mississippi Valley Loess (MLRA 134) of the Lower Mississippi River Valley. It was hypothesized that cover cropping would increase total water-stable soil aggregation and that soils treated without a cover crop would have greater fractions of water-stable aggregates in smaller size classes. It was hypothesized that cover crops would decrease soil bulk density compared to areas without a cover crop. It was also hypothesized that soil pH and SOM would be unaffected by cover cropping after only two seasons compared to areas without cover crops.

Materials and Methods

The current study was part of a larger, multi-year study to evaluate the effects of cover crops over time on a suite of soil physical, chemical, and biological properties across approximately twenty locations throughout eastern Arkansas and western Tennessee where demonstration sites have been established across several MLRAs. The current study focused on a sub-set of five demonstration site locations located only in the Southern Mississippi Valley Loess (MLRA 134), four of which were in eastern Arkansas, and one was in western Tennessee (Figure 1).

Site Descriptions and Management

The management of field treatments, tillage methods, type of cash crop, and cover crop variety used varied slightly across all five locations (Table 1). Each location was divided between a no-cover crop and the cover crop treatment. The primary summer cash crops grown were cotton, soybean, and corn. Cash crops were harvested and followed up by planting and establishment of a cover crop in the fall of each year.

Site one was in St. Francis County near Haynes, Arkansas. This site was initially sampled in December of 2019. Cotton was grown on beds each of the three summers on both the cover crop and no-cover crop treatments. Cereal rye was the cover crop for both Fall 2018 and 2019. The producer at Site one chose to practice a NT system in both the cover crop and no-cover crop treatment areas.

Site two was in Clay County near Piggott, Arkansas. This site was initially sampled in October of 2019. Cash crops included corn and cotton, with corn being grown once in the no-cover crop treatment only with cotton grown on the cover crop treatment in Summer 2018. Cotton was grown on beds as the primary crop in each of the other growing seasons. Cereal rye was the cover crop for both Fall 2018 and 2019. Re-shaped beds were used on the cover crop and no-cover crop treated fields but, samples from the no-cover crop treatments were collected from a stale-seed bed prior to re-shaping.

Site three was in Shelby County at the Shelby Country Agricultural Extension Center, near Germantown, Tennessee. This site was initially sampled in May of 2020. Cotton was grown on beds each of the three production seasons in both the treated and untreated fields. A cereal rye cover crop was used in 2020 but no-cover crop was used in the treated field in 2018. Conventional tillage was used on the no-cover treatment.

Site four was in Cross County near Cherry Valley, Arkansas. This site was initially sampled in December of 2019. Alternating production seasons and starting with corn on both fields, corn and soybeans were grown on beds. Cereal rye, black oats (*Avena strigose*), crimson clover (*Trifolium incarnatum*), and Austrian winter pea (*Pisum sativum subsp. Arvense)* were used as the cover crops both winter seasons. The producer at Site four chose to practice a NT system in both the cover crop and no-cover crop treatment areas.

Site five was in Green County near Paragould, Arkansas. This site was initially sampled in November of 2019. Non-bedded soybeans were grown as the primary cash crop during the three growing seasons in both treatments. A combination of cover crops was used at this site and included cereal rye, black oats, and crimson clover. The producer at Site five chose to practice a conventional tillage system in the no-cover crop treatment area and a no-tillage system in the cover crop treatment.

Experimental Design and Treatments

The experimental design for this study was a completely random design consisting of a single field treatment, with or without cover crops, imposed in five fields at five locations within MLRA 134. The cover crop/no-cover crop treatments were established in either two halves of the same field or in two adjacent fields within the same soil map unit. For certain soil properties, only treatment was formally assessed, while, for other soil properties, soil depth and/or aggregate size class were also formally assessed.

Soil Sample Collection, Processing, and Analyses

Bulk density samples were collected from five random spots (on top of the bed in bedded fields) in each treatment at each location using a 4.7-cm-diameter core chamber and slide hammer from 0- to 10- and 10- to 20-cm depths. Samples were oven-dried at 70^o for 48 hours and weighed for bulk density determinations.

For texture analysis, Mehlich-3 extractable nutrients, soil organic matter (SOM), and soil pH, 25 – 30 individual soil cores were collected throughout the treatment areas to a depth of 15 cm with a 2.5-cm-diameter push probe (from the tops of the beds in bedded fields) and combined into a single composite sample for each treatment area at each location. When field treatment size was larger than 20 acres, the area was divided into two separate composite samples to ensure that no composite sample encompassed more than 20 acres. Soil samples were oven-dried at 70^o C for 48 hours and then crushed to pass through a 2-mm sieve to remove coarse fragments and/or coarse roots. Soil particle-size analyses were conducted using a modified 12-hr hydrometer method to determine sand, silt, and clay concentrations (Gee & Or, 2002). Using the oven-dried, sieved soil, soil pH and Mehlich-3 extractable Ca^{2+}, Mg^{2+}, and Na^{+} and SOM concentrations were also measured. Soil pH was potentiometrically measured using an electrode in a 1:2 (m/v) soil-to-water mixture. Plant-available soil Ca concentrations were determined after extraction using the Mehlich-3 extractant in a 1:10 (m/v) soil-to-solution mixture (Tucker, 1992) and measured by inductively coupled plasma-atomic emission spectrometry (ICP-AES; CIROS CCD model; Spectro Analytical Instruments, MA; SERA-IEG-6, 2014). Soil organic matter concentrations were measured by weight-loss-on-ignition, where a muffle furnace was used for 2 hours at 360^{o}C. The soil did not effervescence when exposed to dilute hydrochloric acid, thus all soil C in the SOM was assumed to be organic C. Measured SOM and Ca, Mg, and Na concentrations were converted to contents using the measured bulk densities and 10-cm sample depth and were reported as either kg or Mg ha^{-1}.

Three random samples were also collected from the top of the bed (in bedded fields) with a 7.4-cm-diameter core chamber and slide hammer from the 0- to 10-cm depth. The core was removed from the chamber and split into 0- to 5- and 5- to 10-cm sections for water-stable aggregate determinations (Smith et al., 2014).

Soil Aggregate Stability Assessment

Following procedures used by Smith et al. (2014), Liu et al. (2005), Dell'Aquila (2007), and Yoder (1936), individual soil samples for aggregate stability were manually broken apart into smaller pieces, sieved moist through a 6-mm mesh screen and left to air dry at ~ 21.1^{o}C for 7 days. After air-drying, 150 g of soil from a sample were weighed and placed on top of the nest of sieves in the wet-sieve apparatus (Figure 2). The nest of sieves contained the following sieve sizes in decreasing order: 4-, 2-, 1-, 0.5-, and 0.25-mm. The nest of sieves was attached to an arm that mechanically oscillated the nest of sieves with the soil sample in a 40-cm-diameter by ~ 120-cm-tall column volume of tap water at 30 cycles per minute for five minutes. After the mechanically imposed disturbance, the nest of sieves was removed and separated. The soil aggregates that had been retained on each sieve were gently manually washed into a pre-weighed, aluminum bread tin with a wash bottle. Samples were left to settle for approximately 10 minutes, excess water was slowly decanted from the tin, making sure no soil aggregates or sediment were poured out of the tin, and the tin was put into a forced-draft oven to oven-dry at 70^{o}C for 24 hours. After oven-drying, tins containing soil samples were weighed to determine the water-stable aggregate fraction by aggregate size class (i.e., > 4-, 2- to 4-, 1- to 2-, 0.5- to 1-, and 0.25- to 0.5-mm sizes) by dividing the oven-dry mass of soil aggregates retained on a sieve by the original 150 g of air-dried soil. Visibly obvious coarse fragments were picked out manually from the largest two size classes, weighed, and the coarse fragment mass was subtracted from the oven-dry soil mass. In addition, total water-stabile aggregates were calculated by summing the mass of soil aggregates retained on all five sieves and dividing by the original 150 g of air-dried soil. The three replications of each soil treatment sample were conducted one after another before the non-aggregated soil that passed through the 0.25-mm sieve was removed from the bottom of the wet-sieve apparatus and the wet-sieve apparatus was filled with fresh water to process the three replications of the next treatment sample.

Statistical Analyses

A one-factor analysis of variance (ANOVA) was conducted using the PROC GLIMMIX procedure in SAS (version 9.4, SAS Institute, Inc., Cary, NC) to evaluate the effect of treatment (cover crop and no-cover crop) on sand, silt, and clay, pH, and extractable soil Ca, Mg, and Na and SOM concentrations and contents. Soil pH and extractable soil Ca, Mg, and Na, and SOM concentrations and contents were analyzed using a gamma distribution, while sand, silt, and clay were analyzed using a beta distribution. A two-factor ANOVA was conducted in SAS to assess the effect of treatment, soil depth (0 to 5 and 5 to 10 cm), and their interaction on the total water-stable aggregate concentration using a beta distribution. Soil bulk density was analyzed using a two-factor ANOVA to evaluate the effect of soil depth (0- to 10- and 10- to 20-cm depths), treatment, and their interaction using a gamma distribution. A three-factor ANOVA was conducted in SAS to evaluate the effects of treatment, aggregate size class (> 4, 2 to 4, 1 to 2, 0.5 to 1, and 0.25 to 0.5 mm), soil depth, and their interactions on water-stable aggregate concentrations using a beta distribution. Significance was judged at $P < 0.05$. When appropriate, means were separated by least significant differences ($P < 0.05$).

Results and Discussion

Initial Soil Properties

Though all five sites contained in this study were from within MLRA 134, initial soil properties in the top 15 cm varied to some degree. Sand ranged from 0.09 to 0.26 g g^{-1}, silt ranged from 0.62 to 0.82 g g^{1}, and clay ranged from 0.07 to 0.16 g g^{-1} among all individual sample replicated across all five sites (Table 2). Even with a range of sand, silt, and clay, the texture of all five sites was a silt loam. Soil pH ranged from 5.9 to 7.2 (Table 2). This range of pH is ideal for most commercial crops and eliminates concern regarding pH-limiting conditions for plants within each of the five sites (NRCS, 1998). Extractable soil Ca ranged from 688 to 1479 mg kg^{-1}, extractable soil Mg ranged from 86.0 to 309 mg kg^{-1}, and extractable soil Na ranged from 7.0 to 29.0 mg kg^{-1} (Table 2). The nutrient concentration ranges among the studied sites are indicative of fertile soil that is in good condition for growing a variety of crops, including the cash crops and cover crops grown in this study (Espinoza et al., 2021). Soil organic matter concentration ranged from 16 to 27 g kg^{-1} (Table 2). Characterizing initial soil properties among sites included in this study showed that most agronomically relevant properties were within a range that is adequate for proper crop growth and production and establishes a baseline condition to which future assessments could be compared to directly quantify and evaluate change-over-time results.

Treatment Effects on Soil Properties

All soil properties measured in the top 15 cm were unaffected ($P > 0.05$) by cover crop treatment (i.e., cover and no-cover; Table 3). Sand, silt, clay, pH, and SOM concentration averaged 0.16, 0.74, and 0.10 g g^{-1}, 6.49, and 20.8 g kg^{-1}, respectively (Table 3). Extractable soil Ca, Mg, and Na concentrations averaged 1043, 184.5, and 14.2 mg kg^{-1}, respectively (Table 3). Sand, silt, and clay are inherent soil properties that were not expected to change due to imposing a cover crop treatment.

The insignificant differences in pH and SOM concentrations between cover crop treatments (i.e., cover crop and no-cover crop) can be attributed to the warm, humid climate of the area and the short duration between treatment establishment and soil sample collection, which was < 24 months across all sites, except the Cross County site, which had treatments in place for approximately four years at the time of sampling. Over a longer period, with consistent management with or without a cover crop, it is expected that the effects of a cover crop treatment would create significant differences between the use of a cover crop and no-cover crop for near-surface soil pH and SOM concentration, as the benefits of cover cropping generally increase over time (Basche et al., 2016, Raper et al., 2000).

Eastern Arkansas has a warm, humid climate with mild winters (NRCS, 2006) that encourages a rapid rate of SOM decomposition (Franzluebbers et al., 2001), especially when the soil is tilled (Desrochers et al., 2019). The climatic factor, in combination with the short duration of the presence of the cover crop treatment, are likely responsible for the lack of SOM concentration differences between cover crop treatments (Table 3). However, the lack of significant differences among initial soil properties across the study sites aids in the evaluation of other dynamic soil properties. Study sites with similar textures, pH, SOM, and extractable soil nutrient concentrations allow for more accurate assessments of vegetative treatments, such as a cover crop or no-cover crop, without concern for how different relatively static soil properties could affect other dynamic soil properties, such as soil bulk density and water-stable aggregate concentration.

Soil bulk density differed between cover crop treatments ($P = 0.03$) and differed between soil depths ($P < 0.01$) (Table 4). Averaged across soil depths, bulk density was greater with no-cover crop (1.27 g cm^{-3}) than with cover crops (1.24 g cm^{-3}) (Table 5). The decrease in bulk density in cover crop-treated fields was likely due to the addition of organic matter in the form of belowground root biomass to increase porosity and reduce compaction and due to the aboveground biomass protecting the soil surface from rainfall impacts (Chalise et al., 2019). Averaged across cover crop treatment, bulk density was 1.1 times greater in the 10-20 cm depth (1.31 g cm^{-3}) than in the 0-10 cm depth (1.20 g cm^{-3}) (Table 5). As plant roots grow between soil aggregates, the roots function as a partitioner and separate the aggregates that have been compacted by farm equipment (Guenette et al., 2019). The difference in depth affected is most likely due to the design of the root systems developed by the cover crops used. The wide, fibrous root systems of cereal rye, oats, clover, and winter pea expand to a shallower depth compared to cover crops with a taproot system and, as a result, the upper 10 cm of the profile had a lower bulk density (Loades, 2010).

Using the measured soil bulk density data with measured concentration data on a sample-by-sample basis, extractable soil Ca, Mg, Na, and SOM contents were calculated. Like concentrations alone, extractable soil Ca, Mg, Na, and SOM contents were unaffected ($P > 0.05$) by cover crop treatment and averaged 1087, 332.3, and 25.4 kg ha^{-1} and 37.3 Mg ha^{-1}, respectively (Table 3).

Water-stable aggregate (WSA) concentrations were unaffected ($P > 0.05$) by cover crop treatment or soil depth (0-5 and 5-10 cm) but differed ($P < 0.01$) among aggregate size classes. Water-stable aggregate concentration in the 0- 0.25-mm size class (0.138 g g^{-1}) was largest and differed among that in the other four size classes (Figure 3). Water-stable aggregate concentration in the 0.50-1.0-mm size class (0.101 g g^{-1}) was greater than that in the 1-2- (0.080 g g^{-1}) and > 4-mm size class (0.053 g g^{-1}) but was like that in the 2-4-mm size class (Figure 3). Water-stable aggregate concentration in the 1-2-mm size class was like that in the 2-4-mm size class (0.085 g g^{-1}) but was also greater than that in the > 4 mm size class, which had the lowest WSA concentration among the five size classes (Figure 3). WSA being unaffected across both cover crop treatment and soil depth is likely explained by the short duration of this study (< 24 months for Sites 1, 2, 3, and 5 and < 48 months for Site 4). Like the results of this study, Smith et al. (2014) reported a general decrease in WSA concentrations with increasing size class in a silt-loam soil in eastern Arkansas after 15 years of consistent management in a wheat-soybean, double-crop system. It was predicted that, if the duration of cover crop treatment was longer, then the effects of cover crop treatment on WSA would be greater. Long-term residue and water management practices, like cover crop treatments, have been shown to aid in the increased soil aggregate stability and result in increased amounts of water-stable aggregates in larger size classes (Smith et al., 2014). Allowing for continuous management with cover crop treatments for 10 years has shown to improve soil properties, including the percent WSA in the 2- to 4- and 1- to 2-mm size classes.

Summing the WSA concentrations across all size classes, and in contrast to soil bulk density, total (TWSA) concentration was unaffected ($P > 0.05$) by cover crop treatment and soil depth (Table 4). Total WSA concentration averaged 0.457 g g^{-1} across all cover crop treatments and soil depths (Table 5). Total WSA concentrations were most likely unaffected by cover crop treatment and soil depth because of the short duration of between establishment and soil sampling for this study. It was expected that within the 24 months that the two seasons of cover crops were implemented few significant changes would have occurred. Like WSA, TWSA would be expected to increase as cover crop treatments continue over time due to the increase in soil aggregate stability and the formation of new and larger soil aggregates. Cover crops aid in the formation of improved soil structure over time and it follows that, as structure improves, an increase in TWSA would occur as well (Dabney et al., 2001; De Baets et al., 2011).

Implications

It is reasonable to assume that, as the duration of cover crop use increases, many of the listed benefits that were insignificant in this study, such as SOM content, would improve in relation to fields without cover crops. This implies that the use of cover crop treatments as a means of improving soil properties is a long-term commitment, and many of the benefits will not be realized in the short-term. The climate in which cover crops are being used should also be taken into consideration, as the time for certain properties to be affected, such as SOM, may vary across climatic zones (Desrochers et al., 2019; Franzluebbers et al., 2001).

As soil aggregate size and strength continue to increase as the duration of cover crop treatment increases, it is also reasonable to speculate that soil erosion potential would decrease. Soils with silt-loam surface texture, such as the ones specifically included in this study, are the most vulnerable soils to wind and water erosion and exist in much of the most productive agricultural areas in the US. This leads to the recommendation that not only should cover crops be used on vulnerable soils, but it is necessary to commit to long-term implementation of cover crops on vulnerable soils if the full benefits of cover crops are to occur.

Conclusions

In general, there is a lack of research surrounding the effects of cover crop treatments on loessal soils, particularly within MLRA 134. This study provided research regarding the effects on physical and chemical soil properties, such as soil pH, SOM, bulk density, extractable nutrients, WSA, and TWSA, with and without cover crops, on highly erodible, silt-loam soils. Results partially supported the hypothesis that the cover crop treatment would increase TWSA and soils without cover crops would have a greater fraction of WSA in smaller size classes. Although WSA significantly differed among size classes, cover crop treatment did not affect WSA concentrations and did not significantly increase TWSA under cover crops. Results also supported the hypothesis that cover crop treatment would decrease soil bulk density compared to the no-cover crop treatment, where soil bulk density differed significantly between treatments and soil depth, with average soil bulk densities in no-cover crop soils 0.03 g cm^{-1} greater than cover cropped soils. Additionally, results supported the hypothesis that soil pH and SOM content would be unaffected by cover crop treatments because of the short duration between cover crop establishment and soil sampling for this study. Although it is expected that if cover crop treatments continued for a longer duration that SOM contents would significantly increase compared to non-cover cropped soils.

Overall, this study indicates that, within the first 24 to 48 months of cover crop treatments, certain soil physical properties, such a bulk density, may begin to improve with the adoption of off-season, cover crop treatment in silt-loam soils. Along with the improvement in bulk density, cover crops provided protection to the vulnerable silt-loam soils within MLRA 134 against wind and water erosion due to canopy cover and root anchoring. The results of this study provide a realistic perspective into the benefits and challenges, mainly those associated with time, of introducing the use of cover crops into MLRA 134.

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Appendix A

Table 1. Summary of site locations, treatments, seasonal and yearly crop descriptions for each site.

County, State	Date of Initial Sampling	Treatment	Cover Crop Year†	2018 Cash Crop	Fall 2018/Summer 2019 Cover Crop	Fall 2018/Summer 2019 Cash Crop	Fall 2019/Summer 2020 Cover Crop	Fall 2019/Summer 2020 Cash Crop
St. Francis, AR	December 2019	No-cover crop	-	Cotton	-	Cotton	-	Cotton
		Cover crop	2018	Cotton	Cereal rye	Cotton	Cereal rye	Cotton
Clay, AR	October 2019	No-cover crop	-	Corn	-	Cotton	-	Cotton
		Cover crop	2018	Cotton	Cereal rye	Cotton	Cereal rye	Cotton
Shelby, TN	May 2020	No-cover crop	-	Cotton	-	Cotton	-	Cotton
		Cover crop	2019	Cotton	-	Cotton	Cereal rye	Cotton
Cross, AR	December 2019	No-cover crop	-	Corn	-	Soybean	-	Corn
		Cover crop	2015	Corn	Cereal rye Black oats Crimson clover Austrian winter pea	Soybean	Cereal rye Black oats Crimson clover Austrian winter pea	Corn
Greene, AR	November 2019	No-cover crop	-	Soybean	-	Soybean	-	Soybean
		Cover crop	2018	Soybean	Cereal rye Black oats Crimson clover	Soybean	Cereal rye Black oats Crimson clover	Soybean

†Cover crops were first established in the Fall of the listed year and were re-established every consecutive fall through 2019.

Table 2. Summary of initial soil property minima and maxima from the top 15 cm across five sites in the Lower Mississippi River Valley.

Soil Properties	**Minimum**	**Maximum**
Sand (g g^{-1})	0.09	0.26
Silt (g g^{-1})	0.62	0.82
Clay (g g^{-1})	0.07	0.16
pH	5.9	7.2
Extractable Ca (mg kg^{-1})	688.0	1479
Extractable Mg (mg kg^{-1})	86.0	309.0
Extractable Na (mg kg^{-1})	7.0	29.0
SOM (g kg^{-1})	16.0	27.0

Table 3. Summary of the effect of cover crop and no-cover crop treatments on soil properties in the top 15 cm across five sites in the Lower Mississippi River Valley.

Soil Properties	***P***	**Cover**	**No-Cover**	**Overall Mean**
Sand ($g\ g^{-1}$)	0.81	0.16 a[†]	0.16 a	0.16
Silt ($g\ g^{-1}$)	0.91	0.74 a	0.75 a	0.74
Clay ($g\ g^{-1}$)	0.95	0.10 a	0.10 a	0.10
pH	0.52	6.55 a	6.43 a	6.49
Extractable Ca ($mg\ kg^{-1}$)	0.97	1041 a	1045 a	1043
Extractable Mg ($mg\ kg^{-1}$)	0.67	176.6 a	192.4 a	184.5
Extractable Na ($mg\ kg^{-1}$)	0.50	15.2 a	13.1 a	14.2
SOM ($g\ kg^{-1}$)	0.64	20.4 a	21.2 a	20.8
Extractable Ca ($kg\ ha^{-1}$)	0.68	1827 a	1919 a	1873
Extractable Mg ($kg\ ha^{-1}$)	0.51	309.0 a	355.5 a	332.3
Extractable Na ($kg\ ha^{-1}$)	0.65	26.7 a	24.1 a	25.4
SOM ($Mg\ ha^{-1}$)	0.44	35.9 a	38.8 a	37.3

[†] Means in a row with different letters are different at $P < 0.05$

Table 4. Summary of the effects of treatment (cover crop and no cover crop), soil depth (0- to 10- and 10- to 20-cm for bulk density and 0- to 5- and 5- to 10-cm for total water-stable aggregates), and their interaction on soil bulk density (BD) and total water-stable aggregates (TWSA) across five sites in the Lower Mississippi River Valley.

Source of Variation	**BD**	**TWSA**
	——— *P* ———	
Treatment	0.03	0.85
Soil depth	< 0.01	0.46
Treatment x soil depth	0.61	0.56

Table 5. Summary of soil bulk density (BD) and total water-stable aggregate (TWSA) means among cover crop treatments and/or measured soil depths across five sites in the Lower Mississippi River Valley.

Treatment/Soil depth	**BD (g cm^{-3})**	**TWSA (g g^{-1})**
Cover	1.24 b†	0.45 a
No-cover	1.27 a	0.46 a
0-10 cm	1.20 b	-
10-20 cm	1.31 a	-
0-5 cm	-	0.45 a
5-10 cm	-	0.47 a

† Means within a treatment group with different letters are different at $P < 0.05$

Appendix B

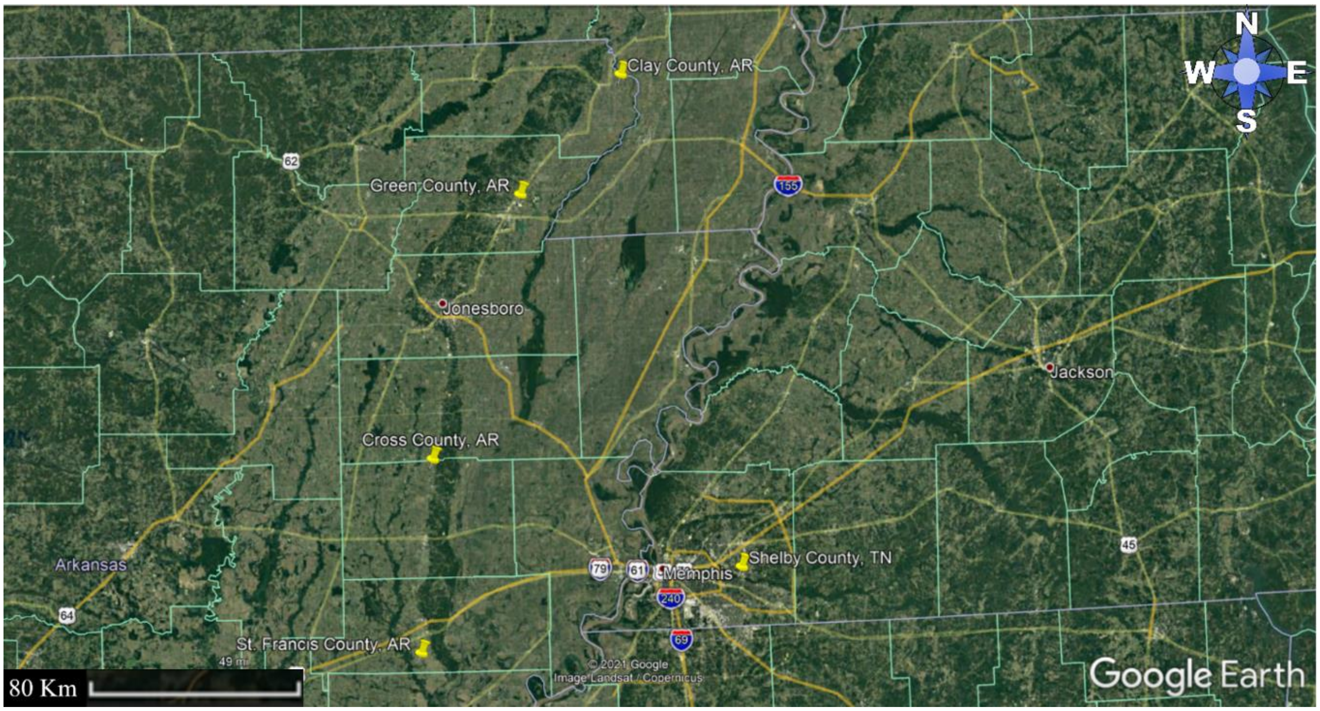

Figure 1. Locations of sample sites (yellow pins) in Major Land Resource Area 134 (Southern Mississippi Valley Loess) in eastern Arkansas and western Tennessee.

Figure 2. Wet-sieve apparatus fitted with nest of five sieves ranging from 4-, 2-, 1-, 0.5-, and 0.25-mm in size. Sieve nest is attached to oscillating arm that allows for movement of sieves through water column at a constant rate controlled by electrical motor and control knob.

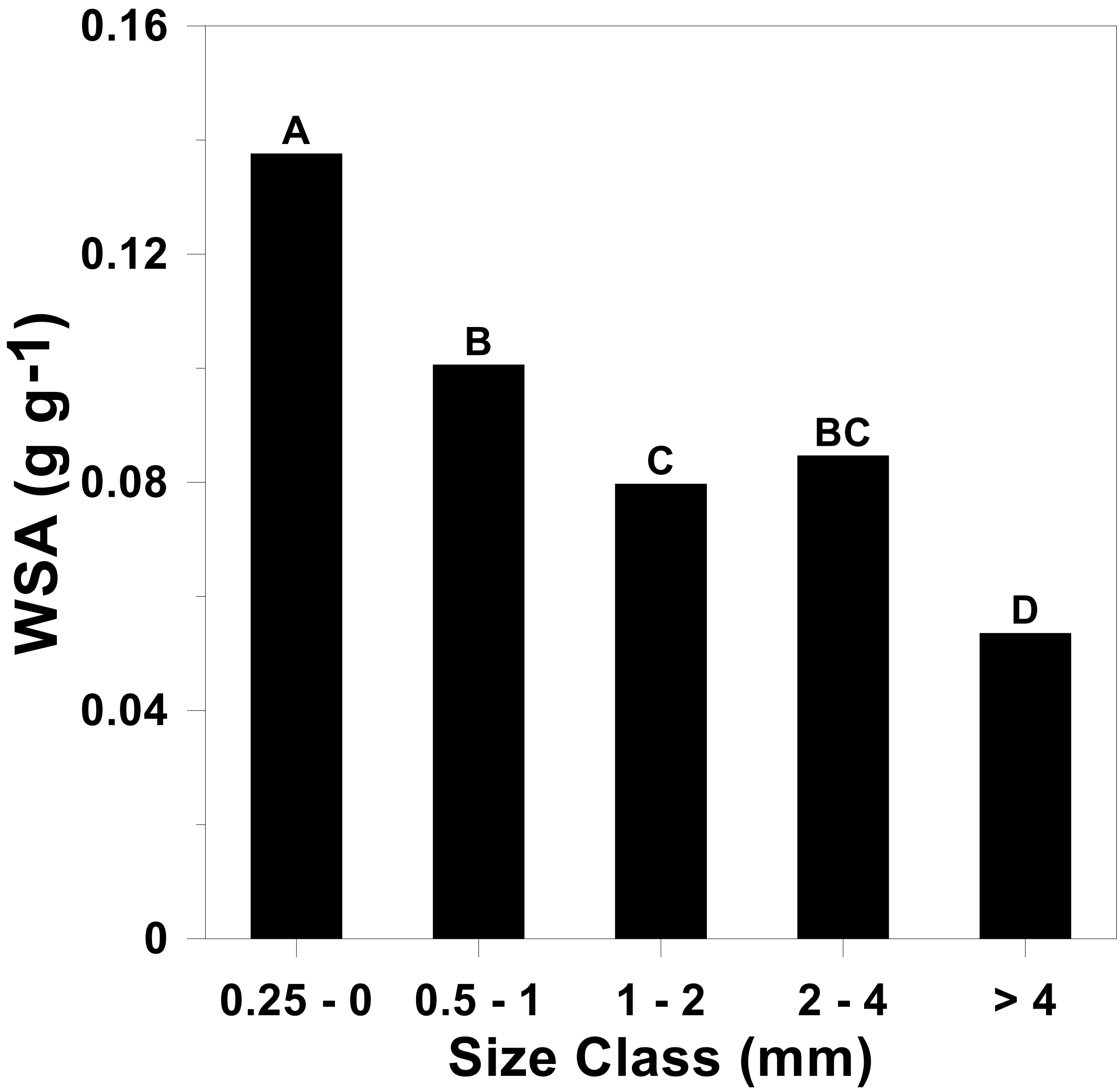

Figure 3. Mean water-stable aggregate (WSA) concentrations among aggregate size classes. Different letters atop bars indicate a significant difference at the $P < 0.05$ level.