Scientific Research Publishing

Agricultural Sciences, 2022, 13, 741-757
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

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

Chandler Arel, Kristofor R. Brye*, Matt Fryer, Mike Daniels

Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, USA
Email: *kbrye@uark.edu

How to cite this paper: Arel, C., Brye, K.R., Fryer, M. and Daniels, M. (2022) Cover Crop Effects on Near-Surface Soil Aggregate Stability in the Southern Mississippi Valley Loess (MLRA 134). *Agricultural Sciences*, **13**, 741-757.
https://doi.org/10.4236/as.2022.136048

Received: May 21, 2022
Accepted: June 25, 2022
Published: June 28, 2022

Abstract

The use of cover crops (CC) during the agricultural fallow period has been shown to help alleviate soil compaction and provide stabilizing effects against soil erosion. These benefits are particularly important as many of the silty, loess-derived soils of the major land resource area (MLRA) 134, the Southern Mississippi Valley Loess, have large erosion potentials. This study evaluated the effects of CC and no-cover crop (NCC) treatments on a selection of silt-loam soils in MLRA 134. Treatments were implemented during Fall 2018 and Fall 2019 and consisted of a range of CC species. Soil samples from the top 10 cm were collected to evaluate a suite of soil properties. Soil texture, pH, soil organic matter, and Mehlich-3 extractable Mg, Na, and Ca were unaffected ($P > 0.05$) by CC treatment. Total water-stable aggregate concentration was unaffected ($P > 0.05$) by CC treatment and soil depth (*i.e.*, 0 - 5 and 5 - 10 cm). Soil bulk density was greater ($P < 0.05$) under NCC (1.27 g·cm^{-3}) than under CC treatment (1.24 g·cm^{-3}). Water-stable aggregate concentration was unaffected ($P > 0.05$) by CC treatment and soil depth, but was 21.5 times greater ($P < 0.05$) in the 0 - 0.25-mm (1.14 g·g^{-1}) than in the > 4-mm (0.05 g·g^{-1}) size class. Study results indicate that, even among sites with large variability, CC can have consistent, short-term, positive effects on soil properties, but a long-term commitment to continuous, annual cover crops is necessary for the full realization of potential benefits.

Keywords

Soil Erosion, Cover Crops, Soil Properties, Soil Aggregate Stability

1. Introduction

Approximately 20% of the land in the United States under agricultural production requires some form of soil restoration, and the use of cover crops as a part of the restoration actions is recommended [1]. The use of cover crops is an ancient practice, and research has revealed how cover crops affect soil and water quality and erosion potential. The complexities associated with cover crops are why further research is warranted, especially as soil conservation is becoming more necessary, and, in some instances, required for certain governmental, cost-sharing, assistance programs, like the Conservation Reserve Program (CRP). The CRP 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 to plant species that improve environmental and soil quality over a contracted period of 10 to 15 years [2].

Soil quality is a complex topic, combining the chemical, physical, and biological properties that affect how soil interacts with the surrounding environment. One common metric often associated with assessing soil quality is the quantification of soil aggregate stability [3]. Soil aggregates form from physical, chemical, and biological processes and are divided into micro (<250 μm) and macroaggregates (>250 μm). However, the formation and stability of soil aggregates is a complex process that is affected by several factors.

Greater soil aggregate stability can positively impact soil hydrologic factors, such as water infiltration, porosity, and soil water storage, while reducing soil erosion and nutrient loss in runoff. 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 [4], 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+}) [5]. The effect of cations on soil structure is disrupted when a large concentration of ions, such as Na^{+}, separate clay particles from binding agents resulting in expansion and dispersion [6] because sodium ions compete for space on clay platelets, but do not flocculate clay particles as Ca^{2+} and Mg^{2+} can. Aggregate formation processes require that SOM exists within the profile, where SOM near the soil surface 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 to facilitate the aggregation of soil particles [7].

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 [5]. 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 [8]. 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 [9]. The creation of aggregate bridges creates a clay fabric that aids in the soil's resistance to slaking and other erosion forces [8].

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 [5]. 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 can improve soil fertility and increase plant-available soil nitrogen concentrations when consistently practiced over time [10]. Cover crops increase SOM when terminated and tilled under as green manure. Similarly, in no-tillage practices, terminated cover crops serve as a protective residue cover that can be planted into the following production season. In such systems, SOM concentrations often increase as the residue layer decomposes. Soil organic matter can even be increased by a harvested cover crop, as plant roots and residues decompose after the grain is harvested and removed from a field [5]. If used as green manure, the cover-crop termination process can be an essential part of recovering degraded soils as nutrients and organic matter are removed during production agriculture.

Soil erosion is a natural process but is exacerbated by 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. Conditions such as increased soil temperature and fast nutrient release from SOM are favorable for crop emergence and growth. However, tillage typically disturbs soil aggregates in the upper 15 cm and increases the potential for water or wind to detach soil particles during erosional events. The decrease in soil erosion potential is attributed to the shallow and widespread portion of the root system provided by grass-type cover crops, as more of the soil matrix becomes entangled by roots, such as with cereal rye (*Secale cereale*) [11].

Turbidity, thought to be from suspended sediment originating from soil erosion from cropland in MLRA 134, is considered the leading cause of water quality impairment of tributaries in the Lower Mississippi River Valley delta region of eastern Arkansas [12]. Beyond natural resource concerns, soil erosion has a direct influence on crop production, as producers routinely have to repair erosion gullies or reform beds to ensure fields can be furrow-irrigated. Additionally, sediment trapped in drainage ditches connected to fields has to be removed for proper, continued water flow. However, the remedial efforts require labor and fuel, as well as incur equipment depreciation costs, that are not routinely considered in the development of crop budgets or cost offsets by conservation practices, such as cover crops. Despite cover crops having several tangible benefits, such as increasing soil aggregate stability, N fixation, decreasing erosion potentials, and sequestering carbon [13], the use of cover crops varies across the United States. Thus, research on the use of cover crops and reduced tillage systems is necessary to ensure soil conservation efforts in the future in locations that have inherent characteristics that are prone to soil erosion, such as in the Southern Mississippi Valley Loess region, major land resource area (MLRA) 134 [14], of the Lower Mississippi River Valley (LMRV).

The Southern Mississippi Valley Loess occupies a total of ~68,686 km^2 across seven states [14]. 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 [14]. The deposition of loess resulted in soils that are generally deep, range from well to somewhat poorly drained, and are loamy textured. The topography of the region is gently sloping, which generally increases in elevation to the west and east away from the Mississippi River. As evidence of past, severe water erosion of the highly erodible, loess-covered landscape of MLRA 134, deep and wide gullies are still visibly present, namely in the eastern Arkansas portion of MLRA 134. Cropland comprises ~36% of the land use in MLRA 134, where much of the area is used for rice (*Oryza sativa*), cotton (*Gossypium hirsutum*), corn (*Zea mays*), and soybean (*Glycine max*) production, in which cultivation is the main soil management practice for all main cash crops. Within MLRA 134, water erosion, maintenance of SOM, and the management of soil moisture are major concerns [14]. Row-crop producers in MLRA 134, such as those that belong to the Arkansas Soil Health Alliance (Personal communication, Adam Chappell, President, Arkansas Soil Health Alliance), are evaluating cover crops as a relatively low-cost way to increase profitability by reducing input costs, with the goal of increasing the rooting depth of the cash crop, water infiltration and water storage, SOM and nutrient cycling and suppressing weed populations.

The integrated effects of cover crops on soils and their interaction with crops and the environment can often be observed visually, but quantifying the differences and detecting significant changes in any one soil property to offer scientific explanations may be much more difficult to ascertain. Research is needed to identify what soil properties are affected by cover crops and how those effects result in greater crop production and natural resource sustainability to develop relevant indicators of influence and expected outcomes. Furthermore, despite being a natural process, water erosion has been a problem for decades because of the accelerated pace at which the erosion occurs due to intensive land use, particularly 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 the disintegration of non-water-stable soil aggregates followed by the transport of non-aggregated, loose soil particles via overland flow (*i.e.*, runoff) within a field and/or to nearby surface waters. Thus, to reduce soil erosion and to improve general soil quality, the implementation of cover crops as a best management practice [15] needs to be evaluated in the highly erodible, loess-covered soils in MLRA 134.

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 LMRV. 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.

2. Materials and Methods

2.1. Soil Descriptions and Management

The management of field treatments, tillage methods, type of cash crop, and cover crop species used varied slightly across five sampled locations in MLRA 134, four of which were in eastern Arkansas, and one was in western Tennessee (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,

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		Fall 2019/Summer 2020	
					Cover Crop	Cash Crop	Cover Crop	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.

and corn. Planting and establishment of a cover crop occurred the fall of each year after commercial crops were harvested.

Site one was in St. Francis County near Haynes, Arkansas. This site was initially sampled in December 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 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 at the Shelby County Agricultural Extension Center, near Germantown, Tennessee. This site was initially sampled in May 2020. Cotton was grown on beds each production season 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 for the no-cover treatment.

Site four was in Cross County near Cherry Valley, Arkansas. This site was initially sampled in December 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 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.

2.2. 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.

2.3. Soil Sample Collection, Processing, and Analyses

Bulk density samples were collected from five random locations, on top of the bed in bedded fields, in each treatment at each field location using a 4.7-cm-diameter core chamber and slide hammer from soil depths of 0 to 10 and 10 to 20 cm. Samples were oven-dried at 70˚C for 48 hours and weighed for bulk density determination [16].

For texture analysis, Mehlich-3 extractable nutrients, SOM, and soil pH, 25 to 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 8.1 ha (20 acres), the area was divided into two separate composite samples to ensure that no composite sample encompassed more than 8.1 ha. Soil samples were oven-dried at 70˚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 [17]. 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 nutrient concentrations (*i.e.*, Ca, Mg. and Na) were determined after extraction using the Mehlich-3 extractant in a 1:10 (m/v) soil-to-solution mixture [18] and measured by inductively coupled plasma-atomic emission spectrometry (ICP-AES; CIROS CCD model; Spectro Analytical Instruments, MA) [19]. Soil organic matter concentrations were measured by weight-loss-on-ignition, where a muffle furnace was used for 2 hours at 360˚C [20]. The soil did not effervesce 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}. Calculations were performed assuming that bulk density was constant from the 0 - 10 and 0 - 15 cm soil depths.

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 [10].

2.4. Soil Aggregate Stability Assessment

Following previous procedures [10] [21] [22] [23], 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˚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. 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 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 manually transferred into a pre-weighed, aluminum container with a wash bottle. Samples were left to settle for approximately 10 minutes, excess water was slowly decanted, making sure no soil aggregates or sediment were discarded. Samples were then placed into a forced-draft oven to oven-dry at 70˚C for 24 hours. After oven-drying, 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. 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. The wet-sieve apparatus was filled with fresh water to process the three replications of the next treatment sample.

2.5. 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 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 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 ($P < 0.05$). All statistical analyses were conducted using SAS version 9.4.

3. Results and Discussion

3.1. Initial Soil Properties

Though all five sites evaluated in this study were from within MLRA 134, initial soil properties in the top 15 cm varied among sites. Sand ranged from 0.09 to 0.26 $g \cdot g^{-1}$, silt ranged from 0.62 to 0.82 $g \cdot g^{-1}$, and clay ranged from 0.07 to 0.16 $g \cdot g^{-1}$ 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 [24]. Extractable soil Ca ranged from 688 to 1479 $mg \cdot kg^{-1}$, extractable soil Mg ranged from 86.0 to 309 $mg \cdot kg^{-1}$, and extractable soil Na ranged from 7.0 to 29.0 $mg \cdot kg^{-1}$ (**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 [25].

Soil organic matter concentration ranged from 16 to 27 $g \cdot kg^{-1}$ (**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 [25].

The soil property dataset generated and evaluated in this study represented a survey of agricultural sites using cover crops for various durations in MLRA 134 within the LMRV, where locations were intentionally selected to result in large variability. Therefore, any resulting significant differences between cover-crop and non-cover-crop treatments will be substantive despite large, inherent, initial, soil property variability.

3.2. 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 $g \cdot g^{-1}$, 6.49, and 20.8 $g \cdot kg^{-1}$, respectively (**Table 3**). Extractable soil Ca, Mg, and Na concentrations averaged 1043,

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 ($g \cdot g^{-1}$)	0.09	0.26
Silt ($g \cdot g^{-1}$)	0.62	0.82
Clay ($g \cdot g^{-1}$)	0.07	0.16
pH	5.9	7.2
Extractable Ca ($mg \cdot kg^{-1}$)	688	1479
Extractable Mg ($mg \cdot kg^{-1}$)	86.0	309.0
Extractable Na ($mg \cdot kg^{-1}$)	7.0	29.0
SOM ($g \cdot kg^{-1}$)	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 ($g \cdot g^{-1}$)	0.81	0.16 a[†]	0.16 a	0.16
Silt ($g \cdot g^{-1}$)	0.91	0.74 a	0.75 a	0.74
Clay ($g \cdot g^{-1}$)	0.95	0.10 a	0.10 a	0.10
pH	0.52	6.55 a	6.43 a	6.49
Extractable Ca ($mg \cdot kg^{-1}$)	0.97	1041 a	1045 a	1043
Extractable Mg ($mg \cdot kg^{-1}$)	0.67	176.6 a	192.4 a	184.5
Extractable Na ($mg \cdot kg^{-1}$)	0.50	15.2 a	13.1 a	14.2
Soil organic matter ($g \cdot kg^{-1}$)	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
Soil organic matter (Mg ha^{-1})*	0.44	35.9 a	38.8 a	37.3

[†]Means in a row with different letters are different at $P < 0.05$. *Measured soil concentrations were converted to contents using measured bulk densities.

184.5, and 14.2 $mg \cdot kg^{-1}$, 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 of consistent management, it is expected that the effects of a cover crop treatment would create significant differences compared to no-cover crop for near-surface soil pH and SOM concentration, as the benefits of cover cropping generally increase over time [26] [27].

Eastern Arkansas has a warm, humid climate with mild winters [14] that encourages a rapid rate of SOM decomposition [28], especially when the soil is tilled [16]. 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 may have been due to the addition of organic matter in the form of belowground root biomass, despite similar SOM contents across treatments, to increase porosity and reduce compaction and due to the aboveground biomass protecting the soil surface from rainfall impacts [29]. 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 [30]. Soil bulk density naturally increases with depth due to the weight of overlying soil, but, in the case of this study, the change in bulk density was likely due to the influence of the CC treatment. 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,

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 $P < 0.05$

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 [31].

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 1873, 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 $g \cdot g^{-1}$) was largest and differed among that in the other four size classes (**Figure 1**). Water-stable aggregate concentration in the 0.50-1.0-mm size class (0.101 $g \cdot g^{-1}$) was greater than that in the 1-2- (0.080 $g \cdot g^{-1}$) and >4-mm size class (0.053 $g \cdot g^{-1}$) but was like that in the 2 - 4-mm size class (**Figure 1**). Water-stable aggregate concentration in the 1 - 2-mm size class was like that in the 2 - 4-mm size class (0.085 $g \cdot g^{-1}$) but was also greater than that in the >4 mm size class, which had the lowest WSA concentration among the five size classes (**Figure 1**). Water-stable aggregates 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). An increasing proportion of small aggregates, as resulted in this study, may increase

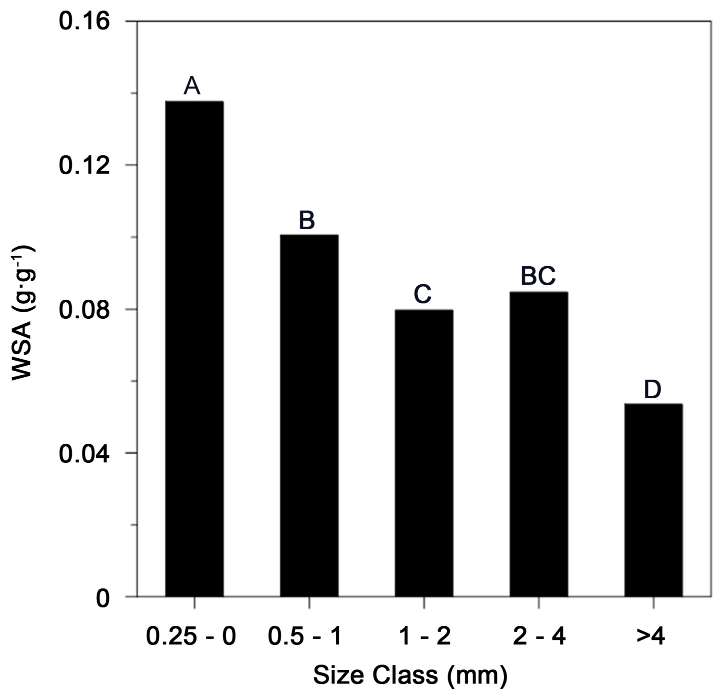

Figure 1. Mean water-stable aggregate (WSA) concentrations among aggregate size classes. Different letters atop bars indicate a significant difference at the $P < 0.05$ level.

aggregate transportability during runoff events to potentially increase soil erosion losses.

Like the results of the current study, Smith *et al.* [10] 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 [10]. 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 $g \cdot g^{-1}$ 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 [32] [33].

3.3. Implications

It is reasonable to expect that, as the duration of cover crop use increases, many of the listed benefits of cover crops that did not differ between cover-crop treatments in this study, such as SOM content and TWSA, would manifest themselves more compared to similar soils without a cover crop [13] [29]. This implies that the use of cover crop treatments as a means of improving soil properties is a longer-term commitment, and many of the benefits will not be realized in the short-term, as was characterized by this study. 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 [16] [28].

Soils with a silt-loam surface texture, such as the ones specifically included in this study, are most vulnerable to soil erosion, particularly water erosion, and exist in much of the most productive agricultural areas in the US. Improving soil structure (*i.e.*, decreasing soil bulk density), root matrix entanglement, and additions of organic matter to the soil from the use of cover crops can potentially contribute to reduced soil erosion and improved overall soil health. Not only should cover crops be used on vulnerable soils, but it is likely necessary to commit to long-term implementation of cover crops on vulnerable soils if the full benefits of cover crops are to occur.

4. Conclusions

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 short-term (*i.e.*, ≤5 years) 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. 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 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 $g \cdot cm^{-1}$ greater than cover-cropped soils. Results also 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. However, 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 the off-season, cover crop treatment in silt-loam soils. From a practical standpoint, this study points out the dilemma of cover crop adoption by agricultural producers for the improvement of soil quality, primarily soil physical and hydrologic properties, as it may take more than 4 years of continuous cover crop use to begin realizing measurable benefits.

Acknowledgements

This work was supported by a grant from the Arkansas Natural Resources Conservation Service. The authors gratefully acknowledge all of the cooperators who allowed soil sampling on their property.

Conflicts of Interest

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

References

[1] Langdale, G.W., Blevins, R.L., Karlen, D.L., McCool, D.K., Nearing, M.A., Skidmore, E.L., Thomas, A.W., Tyler, D.D. and William, J.R. (2014) Cover Crop Effects

on Soil Erosion by Wind and Water. Hawaiian Sugar Planter's Association, Honolulu, 733, 498-525.

[2] United States Department of Agriculture (USDA), Farm Service Agency (FSA). (2022) Conservation Reserve Program. https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/

[3] United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) (2008) Soil Quality Physical Indicator Information Sheet Series. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053287.pdf

[4] Pihlap, E., Steffens, M. and Kögel-Knabner, I. (2021) Initial Soil Aggregate Formation and Stabilization in Soils Developed from Calcareous Loess. *Geoderma*, **385**, Article ID: 114854. https://doi.org/10.1016/j.geoderma.2020.114854

[5] Bronick, C.J. and Lal, R. (2005) Soil Structure and Management: A Review. *Geoderma*, **124**, 3-22. https://doi.org/10.1016/j.geoderma.2004.03.005

[6] Pearson, K. (2003) Basics of Salinity and Sodicity Effects on Soil Physical Properties. https://waterquality.montana.edu/energy/cbm/background/soil-prop.html

[7] La Scala, N., Lopes, A., Spokas, K., Bolonhezi, D., Archer, D.W. and Reicosky, D.C. (2008) Short-Term Temporal Changes of Soil Carbon Losses after Tillage Described by a First-Order Decay Model. *Soil & Tillage Research*, **99**, 108-118. https://doi.org/10.1016/j.still.2008.01.006

[8] Attou, F., Bruand, A. and Le Bissonnais, Y. (1998) Effect of Clay Content and Silt—Clay Fabric on Stability of Artificial Aggregates. *European Journal of Soil Science*, **49**, 569-577. https://doi.org/10.1046/j.1365-2389.1998.4940569.x

[9] Tisdall, J.M. and Oades, J.M. (1982) Organic Matter and Water-Stable Aggregates in Soils. *Journal of Soil Science*, **33**, 141-163. https://doi.org/10.1111/j.1365-2389.1982.tb01755.x

[10] Smith, S.F., Brye, K.R., Gbur, E.E., Chen, P. and Korth, K. (2014) Residue and Water Management Effects on Aggregate Stability and Aggregate-Associated Carbon and Nitrogen in a Wheat-Soybean, Double-Crop System. *Soil Science Society of America Journal*, **78**, 1378-1391. https://doi.org/10.2136/sssaj2013.12.0534

[11] Roberts, T., Ortel, C., Hoegenauer, K., Wright, H. and Durre, T. (2018) Understanding Cover Crops. University of Arkansas, Fayetteville. https://www.uaex.uada.edu/publications/pdf/FSA-2156.pdf

[12] Arkansas Department of Environmental Quality (ADEQ) (2021) Arkansas 303(d) List, 305(b) Report, and Assessment Methodology by Year https://www.adeq.state.ar.us/water/planning/integrated/303d/list.aspx

[13] Abdollahi, L. and Munkholm, L.J. (2014) Tillage System and Cover Crop Effects on Soil Quality: I. Chemical, Mechanical, and Biological Properties. *Soil Science Society of America Journal*, **78**, 262-270. https://doi.org/10.2136/sssaj2013.07.0301

[14] United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). (2006) Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053624

[15] Humphreys, A.E. (2016) Cover Crop Establishment and Potential Benefits to Arkansas farmers. MS Thesis, University of Arkansas, Fayetteville.

[16] Desrochers, J., Brye, K.R., Gbur, E., Pollock, E.D. and Savin, M.C. (2019) Long-Term Residue and Water Management Practice Effects on Particulate Organic Mat-

ter in a Loessial Soil in Eastern Arkansas, USA. *Geoderma*, **337**, 792-804. https://doi.org/10.1016/j.geoderma.2018.10.027

[17] Gee, G.W. and Or, D. (2002) Particle-Size Analysis. In: Dane, J.H. and Topp, G.C., Eds., *Methods of Soil Analysis*, Part 4. Book Series 5, Soil Science Society of America, Madison, 255-293. https://doi.org/10.2136/sssabookser5.4.c12

[18] Tucker, M.R. (1992) Determination of Phosphorus by Mehlich 3 Extraction. In: Donohue, S.J., Ed., *Reference Soil and Media Diagnostic Procedures for the Southern Region of the United States*, Southern Cooperative Series Bulletin No. 374, Virginia Polytechnic Institute & State University, Blacksburg, 6-8.

[19] Southern Extension and Research Activity Information Exchange Group-6 (SERA-IEG-6) (2014) Soil Test Methods from the Southeastern United States. Bulletin No. 419, Clemson University Southern Cooperative Service, Clemson.

[20] Schulte, E.E., Kaufmann, C. and Peter, J.B. (1991) The Influence of Sample Size and Heating Time on Soil Weight Loss-on-Ignition. *Communications in Soil Science and Plant Analysis*, **22**, 159-168. https://doi.org/10.1080/00103629109368402

[21] Liu, A., Ma, B.L. and Bomke, A.A. (2005) Effects of Cover Crops on Soil Aggregate Stability, Total Organic Carbon, and Polysaccharides. *Soil Science Society of America Journal*, **69**, 2041-2048. https://doi.org/10.2136/sssaj2005.0032

[22] Dell'Aquila, R. (2007) Automatic Sieve-Shaker for Determining Soil Aggregate Stability and Dimensional Distribution Using a Vertical Oscillation System. *Italian Journal of Agronomy*, **2**, 401-406. https://doi.org/10.4081/ija.2007.401

[23] Yoder, R.E. (1936) A Direct Method of Aggregate Analysis of Soils and a Study of the Physical Nature of Erosion Losses. *Agronomy Journal*, **28**, 337-351. https://doi.org/10.2134/agronj1936.00021962002800050001x

[24] United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) (1998) Soil Quality Indicators: pH. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052208.pdf

[25] Espinoza, L., Slaton, N. and Mozaffari, M. (2021) Understanding the Numbers on Your Soil Test Report. University of Arkansas, Fayetteville. https://www.uaex.uada.edu/publications/PDF/FSA-2118.pdf

[26] Basche, A.D., Archontoulis, S.V., Kaspar, T.C., Jaynes, D.B., Parkin, T.B. and Miguez, F.E. (2016) Simulating Long-Term Impacts of Cover Crops and Climate Change on Crop Production and Environmental Outcomes in the Midwestern United States. *Agriculture*, *Ecosystems & Environment*, **218**, 95-106. https://doi.org/10.1016/j.agee.2015.11.011

[27] Raper, R.L., Reeves, D.W., Burmester, C.H. and Schwab, E.B. (2000) Tillage Depth, Tillage Timing, and Cover Crop Effects on Cotton Yield, Soil Strength, and Tillage Energy Requirements. *Applied Engineering in Agriculture*, **16**, 379-385. https://doi.org/10.13031/2013.5363

[28] Franzluebbers, A.J., Haney, R.L., Honeycutt, C.W., Arshad, M.A., Schomberg, H.H. and Hons, F.M. (2001) Climatic Influences on Active Fractions of Soil Organic Matter. *Soil Biology & Biochemistry*, **33**, 1103-1111. https://doi.org/10.1016/S0038-0717(01)00016-5

[29] Chalise, K.S., Singh, S., Wegner, B.R., Kumar, S., Pérez-Gutiérrez, J.D., Osborne, S.L., Nleya, T., Guzman, J. and Rohila, J.S. (2019) Cover Crops and Returning Residue Impact on Soil Organic Carbon, Bulk Density, Penetration Resistance, Water Retention, Infiltration, and Soybean Yield. *Agronomy Journal*, **111**, 99-108. https://doi.org/10.2134/agronj2018.03.0213

[30] Guenette, K.G., Hernandez-Ramirez, G., Gamache, P., Andreiuk, R. and Fausak, L.K. (2019) Soil Structure Dynamics in Annual Croplands under Controlled Traffic Management. *Canadian Journal of Soil Science*, **99**, 146-160. https://doi.org/10.1139/cjss-2018-0117

[31] Loades, K.W., Bengough, A.G., Bransby, M.F. and Hallett, P.D. (2010) Planting Density Influence on Fibrous Root Reinforcement of Soils. *Ecological Engineering*, **36**, 276-284. https://doi.org/10.1016/j.ecoleng.2009.02.005

[32] Dabney, S.M., Delgado, J.A. and Reeves, D.W. (2001) Using Winter Cover Crops to Improve Soil and Water. *Communications in Soil Science and Plant Analysis*, **32**, 1221-1250. https://doi.org/10.1081/CSS-100104110

[33] De Baets, S., Poesen, J., Meersmans, J., and Serlet, L. (2011) Cover Crops and Their Erosion-Reducing Effects during Concentrated Flow Erosion. *Catena*, **85**, 237-244. https://doi.org/10.1016/j.catena.2011.01.009