soil systems

Article

Tillage and Cover Crop Systems Alter Soil Particle Size Distribution in Raised-Bed-and-Furrow Row-Crop Agroecosystems

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Abstract: Conservation alternatives that include no-tillage (NT) and cover crops (CCs) reduce soil erosion in row-crop agroecosystems. However, little information is available about how these alternatives affect soil textural properties responsible for soil fertility. This study evaluated the soil particle size distribution and volumetric water content after three years of consistent management in a raised bed system. There were four treatment systems in a dryland maize/soybean rotation on a silt loam soil (Oxyaquic Fraglossudalfs) that included: NT + CCs, conventional tillage (CT) + CCs, CT + winter weeds, and CT + bare soil in winter in northwest Mississippi. The NT + CC system retained 62% more coarse sand in the furrow than the other systems (2.1% compared to 1.3%; $p = 0.02$). Regardless of the location, the NT + CC system (2.5%) retained 39% more fine sand than the CT + CC system (1.8%; $p = 0.01$), suggesting that coarse and fine sands were being trapped in furrows combining NT + CC systems, minimizing their off-site transport. In furrows, CCs increased soil volumetric water content by 47% compared to other winter covers. In beds, NT + CCs increased bed water contents by 20% compared to CT + CCs (17.1 to 14.3%; $p < 0.01$). Implementing conservation alternatives may promote the retention of sand fractions in silty loam soils that are important in supporting soil fertility and crop sustainability.

Keywords: soil texture; soil erosion; soil water-holding capacity; Mississippi

Citation: Jacobs, A.A.; Stout Evans, R.; Allison, J.K.; Kingery, W.L.; McCulley, R.L.; Brye, K.R. Tillage and Cover Crop Systems Alter Soil Particle Size Distribution in Raised-Bed-and-Furrow Row-Crop Agroecosystems. *Soil Syst.* **2024**, *8*, 6. https://doi.org/10.3390/soilsystems8010006

Academic Editor: Ewald Schnug

Received: 27 November 2023
Revised: 18 December 2023
Accepted: 21 December 2023
Published: 5 January 2024

1. Introduction

Two main agricultural production and sustainability issues with row-crop production in the Southeastern United States are sediment erosion and the subsequent loss of soil fertility over time. The loss of productive soil is widely highlighted as one of the most important sustainability challenges of the future [1,2]. In the Lower Mississippi Delta region, maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] production is often facilitated by supplemental irrigation from groundwater or surface water sources, necessitating conservation practices to increase crop water use efficiency [3]. Many producers in the area construct raised beds in fields to promote adequate soil drainage for spring planting and to increase irrigation efficiency [4].

In addition to crop water management, runoff from both dryland and irrigated systems can carry excess sediment and nutrients to adjacent watersheds in the Mississippi River Basin [5]. Reducing soil erosion from cropland agroecosystems has long been a primary natural resource goal by encouraging management strategies that promote soil retention and soil fertility. The retention of soil nutrients essential for crop growth depends largely on reducing the losses of basic soil textural components—sand, silt, and clay [6]. The adoption of no-tillage (NT) regimes has been widely shown to reduce sediment loss [7]. Tillage has also been shown to change the proportions of sand, silt, and clay in cropland systems [8]. In addition, the adoption of cover crops (CCs), crops that are grown for soil benefits rather than as a cash crop, has been shown to reduce soil erosion and nutrient loss [9]. Combining NT and CCs has additionally been shown to conserve soil water by supporting adequate soil pore space, infiltration, and drainage [10].

While the effects of NT and CCs on soil organic matter, crop yield, soil bulk density, field-scale soil erosion, crop production costs, and crop pest pressure have been previously evaluated [10–12], there is little information about how these systems affect the near-surface soil texture and particle size distribution, particularly where raised beds and furrows have been constructed to facilitate furrow irrigation. The overall soil surface texture determines many aspects of cropland soil fertility and agroecosystem functioning [13], such as water infiltration rate and drainage, nutrient holding capacity, erosion susceptibility, water-holding capacity, and habitat suitability for soil microbial communities. Raised bed systems impart additional management challenges that can stratify other physical and soil properties such as pH, electrical conductivity, and soil nutrients available for plant growth [14], necessitating the finer-scale study of conservation practices on bed and furrow soil resources.

The surface soil texture and the proportions of sand, silt, and clay in crop agroecosystems are thought to be generally insensitive to site management changes [15]. However, soil particles of all sizes are susceptible to transport via wind and water, with removal and deposition occurring in fields and potentially off-site. The unique microenvironments of the raised-bed-and-furrow systems are typically maintained by regular tillage, which can change the distribution of sand, silt, and clay particles. The retention of sand in near-surface soils is necessary for timely infiltration in the bed to be absorbed by the growing crop, as well as in the furrow to be absorbed quickly for efficient furrow-based irrigation water distribution across the field. Anecdotal evidence from the Mississippi Delta region suggests that a primary reason agricultural producers who practice furrow or dryland irrigation in raised bed systems are interested in cover crops is to preserve the bed height and integrity over the winter. Planting winter cover crops helps prevent bed erosion, which may save producers from having to refurbish eroded beds prior to planting in the spring.

The effects of cover crops on near-surface soil particle size distributions have not been evaluated. Investigations into the effects of basic and commonly recommended conservation practices such as no-till and cover crops on the proportions of sand, silt, and clay, the foundations of soil fertility and crop productivity, are largely absent in the scientific literature. The soil bulk density in raised bed systems did not change over a three year period with the implementation of NT and CCs [11]; however, tracking soil particle changes may provide better information about localized erosion than other soil physical parameters such as bulk density. Extensive tillage over decadal time periods has been shown to reduce the sand content and increase the clay content due to particle mechanical breakdown and transport induced by a long history of continuous tillage compared to adjacent undisturbed prairie soils [16]. However, the effects of NT and CC systems on localized erosion and the resulting soil particle size distribution within raised bed systems has not been investigated in an agronomic context. The implications of changes to the proportions of surface sand, silt, and clay may alter important soil properties such as the soil cation exchange capacity, electrical conductivity, and resistance to erosion. Tracking changes in proportions of each may change overall soil horizon classifications (e.g., from a silty loam to a loam) and subsequent fertilizer and herbicide recommendations [17].

The objective of this study was to evaluate the effect of cover crops and tillage on the soil particle size distribution and associated soil water contents in raised-bed-and-furrow row-crop agroecosystems in the Mississippi Delta region of northwest Mississippi.

It was hypothesized that conservation systems limiting erosion, namely NT and CCs, would alter the near-surface soil particle size fractionations and soil water contents over the crop growing season and would depend on the bed or furrow location in the field. Hypotheses were generated after observing the visual soil surface variations between the plot-level treatments in terms of the coarse sands and silt present when viewed from above. Qualitatively, the surfaces of plots combining NT and CC systems appeared to have greater coarse sand fractions than CT and non-CC plots, leading us to hypothesize that coarse sediments may be greater in systems with these conservation practices. In addition, we hypothesized that NT and CC systems would retain greater soil moisture contents than CT and non-CC systems.

2. Materials and Methods

2.1. Site Description

The study was located at the United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) Jamie L. Whitten Plant Materials Center, near Coffeeville, MS (33°59′01″ N; 89°48′16″ W). The mean annual precipitation in Coffeeville for the past 30 years was 149 cm, where the majority of precipitation occurred in winter (28%) and spring (27%) compared to summer (22%) and fall (23%) [18]. Monthly mean precipitation and temperature values during the study from 2015 to 2018 in nearby Water Valley, MS, were, respectively, as follows: Jan (12 cm, 4.2 °C), Feb (26 cm, 7.8 °C), Mar (17 cm, 12.8 °C), Apr (16 cm, 14.1 °C), May (16 cm, 23.3 °C), Jun (9 cm, 26.4 °C), Jul (8 cm, 27.5 °C), Aug (16 cm, 26.3 °C), Sep (8 cm, 23.3 °C), Oct (6 cm, 19.6 °C), Nov (19 cm, 11.4 °C), Dec (16 cm, 8.0 °C) [19].

The soil at the site was a Grenada silt loam (fine-silty, mixed, active, thermic Oxyaquic Fraglossudalfs; [20]). The Grenada soil series is a loessal soil, sensitive to accelerated erosion, and is formally designated as highly erodible land when slope values are greater than 2% slope [21]. Spring soil drainage is slow because a fragipan is present at a depth of ~45 cm. Soybean and maize crops in this area are usually planted in raised-bed systems to allow for better drainage and better conditions for early spring planting. This soil series in northwest Mississippi has previously been reported to have lost 40–80% of topsoil above the fragipan due to extensive erosion since original cultivation [22].

2.2. Tillage and Cover Crop Systems

The study site was prepared in 2015 by using tillage to construct raised beds on 101.6 cm row centers and 100 m in length and managed as a soybean–maize rotation. Soybeans were planted in 2015 and 2017 and maize was planted in 2016 and 2018. Previously, the site vegetation was a mix of warm-season pasture grasses and forbs that was mowed twice per year.

Field treatments consisted of three winter cover types and two tillage regimes in a 2 × 3 factorial design with four replications. Winter cover types included (1) bare, which was controlled with soil-applied herbicides in the fall to prevent volunteer winter weed establishment; (2) winter weeds, where volunteer winter annual weeds were allowed to germinate with no herbicide application; and (3) cover crop, where winter cover crops were broadcast-seeded after cash-crop harvest. Cover crop species mixes varied and were designed using the USDA-NRCS Cover Crop Selection Tool [23], but included cereal rye (*Secale cereale* L.), crimson clover (*Trifolium incarnatum* L.), and daikon radish (*Raphanus sativus* L.) in 2016, cereal rye and rapeseed (*Brassica napus* L.) in 2017, and wheat (*Triticum aestivum* L.) and crimson clover in 2018. Winter vegetation in plots (either winter annuals or cover crops) were chemically terminated with aerially applied broad spectrum herbicide prior to planting cash crops. Additional details regarding species cultivars, cover crop termination methods and herbicide rates, and seeding rates were reported in Jacobs, Evans, Allison, Garner, Kingery, and McCulley [11].

Each winter cover treatment type was paired with either conventional tillage (CT) or NT management. Conventional tillage consisted of new bed construction in 2016 and 2018 by leveling existing rows using an offset disc harrow. Bed rows were then reconstructed using a disc bedder hipper before maize planting. In the NT regime, soil beds were not disturbed after initial establishment in 2015, except with fluted coulters attached to cash-crop planting equipment. Rows (beds and furrows) were maintained in their precise location throughout the study duration. Crop yields, routine soil analyses, soil organic matter, soil bulk density, specific tillage implement details, and crop production costs have been previously reported [7].

2.3. Soil Sampling and Soil Moisture Measurements

For this study, only a subset of the full 2 × 3 factorial treatment combinations was sampled for soil particle size distribution and soil moisture assessment due to limitations in funding and personnel labor. Selected treatments included CT + bare, CT + winter weeds, CT + cover crop, and NT + cover crop with more CT plots than NT plots sampled as CT is the predominant tillage regime in the study area [11]. On 3 May 2018, surface soil of beds and furrows was collected to a depth of 3 cm using a custom-fabricated, three-sided, stainless-steel pan. Pan dimensions were 10 cm in length × 10.2 cm width × 4.9 cm height. Soil was sampled by pushing the open end of the pan horizontally into the soil profile wall (in the bed or furrow) and removing pan with soil sample intact in pan. Soil was sampled between maize plants on beds and within furrow bottoms, where furrow soil was collected immediately downslope and adjacent to bed samples. Surface residue and plant material was manually removed. Five subsamples from each plot were collected and composited by mixing in a small bucket, with bed and furrow samples kept separately. Soil samples for particle size analysis were selected randomly within the two inner raised beds and furrows of each four-row wide plot, along the 90 m plot length. Lists of annual field activities and seedbed preparation are detailed further in previous site descriptions [11].

Soil moisture was measured at bed and furrow locations beginning in July through early September 2018 during maize production. The maize crop was planted on 13 April and harvested on 28 August 2018. Volumetric water content was measured twice monthly in bed and furrow locations in each plot from July to early September for a total of five sampling times using a FieldScout TDR 350 soil moisture meter with 7.6 cm rods (Spectrum Technologies, Aurora, IL, USA). Three measurements from each plot for bed and furrow locations were recorded and averaged for each plot.

2.4. Soil Particle Size Fractionation

A subsample of collected soil was oven-dried (55 °C) for two to three days, crushed, and then sieved to pass through a 2 mm screen to determine total proportions of sand (0.05–2 mm), silt (002–0.05 mm), and clay (<0.002 mm) using a modified 12-h hydrometer method using 50 g of soil [24]. Sand fractionation was performed using a wet-sieving procedure after the 12-h hydrometer method was performed. Sediments were separated into sand sub-classes after oven-drying and weighing the material that was retained on mesh sizes of 1 (very coarse sand), 0.5 (coarse sand), 0.25 (medium sand), 0.11 (fine sand), and 0.05 (very fine sand) mm [25].

2.5. Data Analyses

Soil particle size distributions (total sand, silt, and clay, and sand fractionation categories of very coarse, coarse, medium, fine, and very fine sand) were analyzed using a 2-factor analysis of variance (ANOVA) with replication block as a random effect. Fixed effects included treatment system (CT + bare, CT + winter weeds, CT + cover crop, and NT + cover crop), location (bed and furrow), and their interaction.

Volumetric water content was analyzed using measurement day, treatment system, location, and their interactions in a linear, mixed-effects model with repeated measure analysis. The mixed-effects model was modified with an order-one autoregressive correlation covariance structure (AR1) to better compare time series measurements [26]. Data were analyzed in R (R version 4.3.1; [27]) and compared using a linear mixed-effect model with the lmer function from the lme4 [28] and lmerTest packages [29]. Means were separated with Tukey's HSD at the 0.05 level using emmeans and multcomp functions in R. Means presented are ±standard error of the means.

3. Results

3.1. Total Sand, Silt, and Clay Contents

The total sand, silt, and clay fractions in the top 3 cm were not affected by the cover and tillage treatment system, nor by the interaction of the treatment system and location ($p > 0.05$; Table 1). However, the total clay and total sand differed between the locations ($p < 0.05$; Table 1). The total clay was 1.2 times greater in the beds (9.1% ± 0.5%) than in the furrows (7.4% ± 0.4%; $p = 0.011$), while the total sand was 1.1 times greater in the furrows (18.6% ± 0.6%) than in the beds (17.1% ± 0.5%; $p = 0.032$; Figure 1). The total silt content was unaffected by the location or treatment and averaged 74% (±4%) across all the treatments.

Table 1. Analysis of variance summary of the effects of treatment (conventional till + bare, conventional till + winter weeds, conventional till + cover crop, and no-till + cover crop), location (bed and furrow), and their interaction on total sand, silt, and clay fractions and sand sub-classes. F-values are F-test statistics for analysis of variance. Bolded *p*-values are below the significance level of 0.05.

Soil Parameter	Treatment		Location		Treatment × Location	
	p	F-Value	*p*	F-Value	*p*	F-Value
Total sand	0.0833	2.6	**0.0315**	5.4	0.2427	1.5
Total silt	0.3017	1.3	0.8491	0.0	0.4457	0.9
Total clay	0.4603	0.9	**0.0110**	7.9	0.57903	0.7
Sand, very coarse	0.1311	2.1	0.6206	0.3	0.1285	2.1
Sand, coarse	**0.0285**	3.8	0.1384	2.4	**0.01785**	4.3
Sand, medium	0.1878	1.8	**0.005**	10.1	0.5950	19.0
Sand, fine	**0.009**	**5.2**	**0.0001**	23.3	0.8066	19.0
Sand, very fine	0.1767	1.8	**0.0033**	11.4	0.8392	18.2

Figure 1. Surface soil particle size analysis in beds and furrows for (**a**) total clay content; (**b**) total sand content. Bars represent standard error of the means. Different letters within a panel indicate a significant difference and *p*-values of <0.05 were considered significant.

3.2. Sand Fractionation

Apart from the very coarse sand, the other four sand sub-classes were affected by the treatment, location, or both (Table 1). The coarse sand differed between the locations among the treatment systems ($p = 0.018$), where there were no coarse sand content differences among the treatment systems in the bed. However, the coarse sand in the furrow was 62% greater in the NT + cover crop (2.1%) than in all other treatments (1.3%; $p = 0.02$; Figure 2). Averaged across the locations, the fine sand was 39% greater ($p = 0.01$; Table 1) in the

NT + cover crop system (2.5%) compared to the CT + cover crop (1.8%), and CT + bare (1.9%) systems, which did not differ (Figure 3).

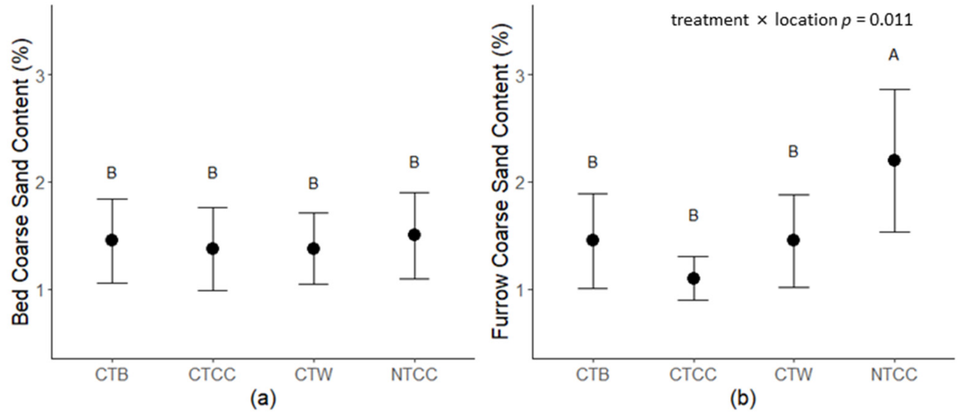

Figure 2. Coarse sand contents in surface soils with treatments: conventional tillage + bare (CTB), conventional tillage + cover crop (CTCC), conventional tillage + winter weeds (CTW), and no-till + cover crop (NTCC) in (**a**) row beds and (**b**) row furrows. Bars represent standard error of the mean and different letters across both panels indicate significant differences at the 0.05 level.

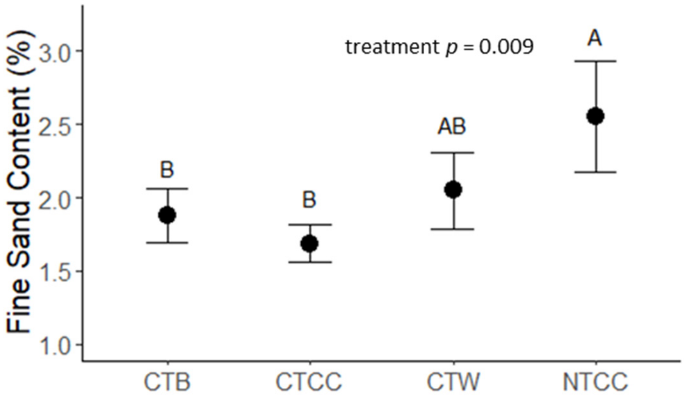

Figure 3. Fine sand content in surface soils with treatments: conventional tillage + bare (CTB), conventional tillage + cover crop (CTCC), conventional tillage + winter weeds (CTW), and no-till + cover crop (NTCC) averaged across beds and furrows. Bars represent standard error of the mean and different letters above means indicate significant differences at the 0.05 level.

Averaged across the treatments, the total sand content was 1.1 times greater in the furrows (18.6% ± 0.57%) compared to the beds (17.1% ± 0.48%). Similarly, this trend was also reflected in greater contents in the furrows of medium sand (2.4% ± 0.18%) compared to the beds (1.9% ± 0.11%), fine sand (2.4% ± 0.19% in the furrow, and 1.7% ± 0.10% in the bed, respectively), and very fine sand (3.2% ± 0.22% and 2.4% ± 0.13%, furrow vs. bed, respectively; $p < 0.05$; Table 1). Similar to the total silt, very coarse sand was unaffected by the location or treatment and averaged 2.8% (±0.15%) across all the treatments.

3.3. Volumetric Water Content

The volumetric soil water contents in the top 7.6 cm differed between the locations over time ($p < 0.001$; Table 2), with the water contents generally greater in July and declining through September in both the beds and furrows. The water contents were greater in the furrows than in the beds for all the measurement dates except the first day (3 July 2018; Figure 4).

The treatment and location interacted to affect the soil volumetric water content ($p < 0.01$; Table 2). In the furrows, the soil water content was maximized by implementing a cover crop regardless of the tillage regime (NT + cover crop and CT + cover crop mean of 20.9%) compared to the conventional till + bare and conventional till + winter weeds, which averaged 14.2% and did not differ from each other (Figure 4). However, in the beds, combining cover crops with no tillage maximized the soil water content (17.1%) compared to the conventional till + cover crop (14.3%; Figure 5).

Table 2. Analysis of variance summary for the effects of treatment, measurement day, location, and their interactions on volumetric soil water contents. F-values are F-test statistics for analysis of variance. Bolded *p*-values are below the significance level of 0.05.

Source of Variation	*p*	F-Value
Treatment	<0.001	62.4
Measurement day	<0.001	90.7
Location	<0.001	99.1
Treatment × measurement day	0.289	1.2
Treatment × location	**<0.001**	12.9
Measurement day × location	**<0.001**	3.9
Treatment × measurement day × location	0.910	0.5

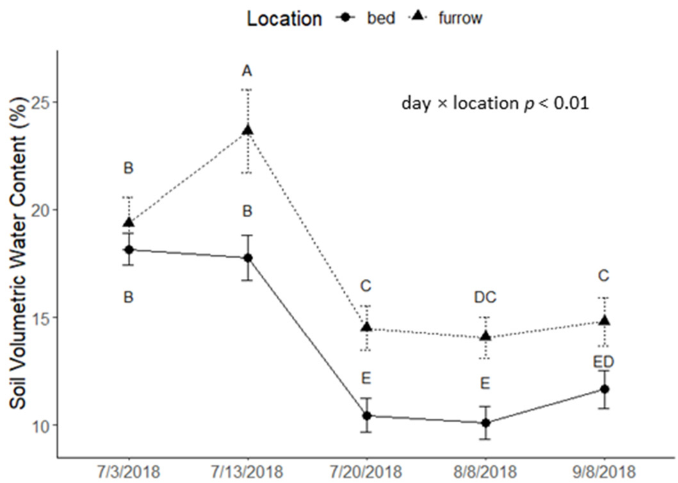

Figure 4. Soil volumetric water contents in maize crop beds and furrows from July to September 2018. Bars represent the standard error of the mean and different letters above means indicate significant differences at the 0.05 level.

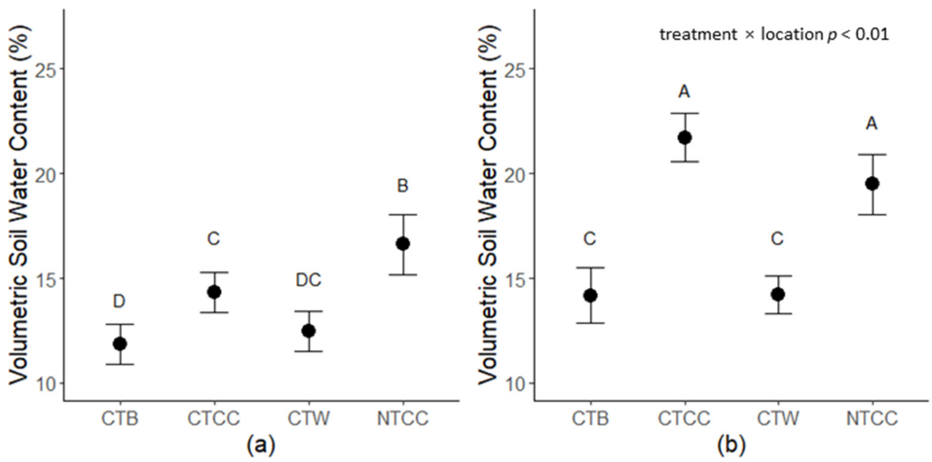

Figure 5. Soil volumetric water content in maize crop (**a**) beds and (**b**) furrows from July–September 2018 with cover and tillage treatments: conventional tillage + bare (CTB), conventional tillage + cover crop (CTCC), conventional tillage + winter weeds (CTW), and no-till + cover crop (NTCC). Bars represent standard error of the mean and different letters across both panels indicate significant differences at the 0.05 level.

4. Discussion

The results of this study show that even after only three years, raised-bed, row-crop production systems can stratify the distribution of soil textural particles and soil water contents between beds and furrows, which generally supports our hypothesis that management is capable of altering soil particle fractions. This is in contrast to the general assumptions that soil particle fractions are largely insensitive to short-term management effects [15,16]. The total clay was greater in the beds and the total sand was greater in the furrows. Over a three-year period, the winter cover management and tillage regime altered the in-field proportions of the sand sub-fractions in a raised-bed system on a highly erosive, silt-loam, loessial soil. It is important to note that the textural changes we observed did not change the overall soil textural class—all the treatments remained in the sand, silt, and clay proportions for a silty loam [25]. We speculate that the surface textures could possibly change given longer-term timescales, as this study recorded the shifts (albeit at a finer scale) in only three years.

In contrast to our hypothesis, the bed locations did not contain greater coarse sand fractions (medium, coarse, very coarse sand) in the NT + CC systems compared to the CT systems, as the treatments appeared to alter the coarse sand fractions more strongly in the furrow locations. However, a greater proportion of fine sand was present in the NT + CC treatments compared to the CT systems with winter weeds or left bare, which partially supports our initial visual observation of greater coarse sand fractions in the NT + CC beds compared to other systems.

Coarse sand was 62% greater in the NT + CC furrow compared to other systems, indicating that coarse sand particles may be trapped by cover crops and maintained by reduced tillage, likely preventing the transport and loss from the field. The no-till + cover crop systems retained more coarse sand in the furrow and fine sand regardless of the bed or furrow location compared to the CT + cover crop systems, indicating that a lack of disturbance, and not merely providing vegetative cover over the winter, is necessary to trap particles and retain coarse and fine sands within the field. Surface residue in the NT systems may have contributed to the trapping of sand particles in the furrows, as residue covering soil has been shown to be essential for limiting cropland erosion [30]. Previously reported results from this study site showed that increasing the residue canopy groundcover above 20% was effective in limiting the estimated soil loss to levels considered tolerable for participation in cropland USDA Farm Bill programs [11].

An alternative and plausible explanation for the increase in the coarse sand percentage in the furrows in the NT + CC treatment system is that the furrows in this system lost more fine silts and clays, thereby increasing the corresponding proportion of coarse sand fractions in the soil. Losses of fine particles in the NT + CC furrows may be due to the cumulative water erosion of fine soil particles in the furrow. Tillage in CT plots may have temporarily replenished the fine soil particles (silts and clays) with disturbance, with the NT plots being undisturbed.

Increases in the amount of sand retained may have contributed to greater soil water contents if the surface water infiltration was improved. The implementation of NT has previously been shown in a meta-analysis to alter soil macro and micropores by decreasing the total soil porosity and microporosity and increasing the microporosity in the top 20 cm of soil [31], though porosity changes were not tracked with the soil particle size analyses. Winter cover crops, such as cereal rye, have been previously shown to increase the soil water contents for cash crops [32]. Sand particle increases in the furrows of the NT + cover crop systems may have increased the soil porosity and potentially greater water storage in the top three cm of soil. It should be noted that the soil moisture contents in the furrows were expected to be greater than those in the beds due to a variety of factors (e.g., lower crop root density, etc.). We expected the bed and furrow soil water contents to be different regardless of the treatments imposed. The impact of the treatment system on the soil water contents depended on the location. In the beds, the soil water contents were greater in the NT + cover crop system compared to the CT + cover crop system, while the soil water contents under both tillage regimes with cover crops in the furrows did not differ (Figure 4).

These results show that the implementation of both NT and cover crops may be necessary to maximize soil water content in beds, but only cover crops may be needed in CT regimes to maximize soil water in furrows. From a soil moisture standpoint, growing winter cover crops in either tillage regime promoted greater soil water contents in the furrow (Figure 5). Cover crops, either by preserving soil pore space or increasing soil surface residue and subsequent soil water evaporation, increased the soil water content for the maize crop.

Previously reported findings from this study showed that these treatment systems did not affect the soil organic matter or soil bulk density, but that implementing cover crops and no-tillage reduced the estimated field erosion [11]. This study showed that the soil remaining on-site with the implementation of these conservation management systems are coarse and fine sand fractions. However, one alternative interpretation would be that the significant decline we observed in the furrow clay content may itself partially explain the increase in the furrow sand proportion that we observed. Since this study did not characterize the edge-of-field soil losses, it is not possible to identify which particles left the field via water erosion. Regardless, these results show that surface soil particle proportions are dynamic in raised bed cropland systems.

Changes in soil particle sub-classes over time may further affect many aspects of overall soil health and functioning, including soil fertility, surface infiltration rate, and eventually crop yield. Previously reported results from this study found that changes in the soil pH within management systems affected the soil fungal community composition [33], possibly showing a potential connection between the soil surface particle distribution and soil microbial communities.

5. Conclusions

Overall, this study demonstrated that conservation practices that include reduced tillage and cover crops can modify soil particle size distributions in raised-bed systems on highly erodible soils within the relatively short period of three years. The results show that physical soil properties, such as soil particle size distribution, that are widely considered to be insensitive to crop management may, at least at a finer plot scale, be altered by common management practices, such as winter cover type and tillage regime. Further investigation is needed to determine the particle size changes associated with twin-row raised beds, which are becoming more popular in the Mississippi Delta [4]. In addition, different combinations along the spectrum of conservation practice implementation (e.g., NT regimes that are bare during the winter) should be evaluated for impacts on soil texture, since producers routinely implement customized tillage and winter vegetation management systems. The use of limited-disturbance tillage regimes that maximize soil cover with winter vegetation are recommended to trap coarse and find sand particles and prevent both localized erosion from beds to furrows and off-site transport from fields, generally promoting greater sustainability in row-crop agroecosystems.

Author Contributions: Conceptualization, A.A.J., R.S.E., J.K.A. and W.L.K.; methodology, A.A.J., R.S.E. and K.R.B.; formal analysis, A.A.J., R.L.M. and K.R.B.; investigation, A.A.J., R.S.E., J.K.A. and K.R.B.; resources, A.A.J., K.R.B. and R.L.M.; data curation, A.A.J.; writing—original draft preparation, A.A.J.; writing—review and editing, K.R.B., R.S.E., R.L.M., J.K.A. and W.L.K.; visualization, A.A.J.; supervision, A.A.J. and R.L.M.; project administration, A.A.J.; funding acquisition, A.A.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the USDA-NRCS Plant Materials Program.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We thank Lane Kimbrough, Tommy Moss, Delon Price, Abigail Allison, Brigg Brasher, and the Professional Soil Classifiers of Mississippi for field assistance, Victoria Stanton and Jim Nelson for general statistical information, Ramona Garner for general study design expertise, Joel Douglas for technical assistance related to plot management, and John Englert for national USDA program funding and administration.

Conflicts of Interest: The authors declare no conflicts of interest.

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