===== **SOIL PHYSICS** =====

Changes in Soil Hydro-Physical Properties by Cover Crops Relative to Tillage Management

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Abstract— Cover crop management practices have a critical impact for long-term sustainable soil productivity due to their positive effects on soil hydro-physical properties. The aim of the study was to evaluate the changes of water retention, pore-size distributions, saturated hydraulic conductivity (K_s), and bulk density values of soil samples collected before and after tillage in response to cover crop (CC) and no-cover crop (NCC) treatments. Research was conducted on a silt loam soil in Chariton County, Missouri, United States. Hairy vetch (*Vicia villosa* Roth.), red clover (*Trifolium pretense*), turnips (*Brassica rapa* L.), buckwheat (*Fagopyrum esculentum*), cereal rye (*Secale cereals* L.), winter peas (*Lathryrus hirsutus* L.), barley (*Hordeum vulgare* L.), triticale (*Triticale hexaploide* Lart.), radish (*Raphanus sativus* L. var. *longipinnatus*), and cowpeas (*Vigna unguiculata*) were used as the CCs. Soil sampling was performed in two different periods (spring/summer) from six replicate locations for each treatment using a grid sample design. Results showed that CC treatment had significantly greater water content in first samples for some pressures (0.0, −2.5 and −1500 kPa) and in second soil samples for all pressures. Total pores and macropores were significantly greater under CC treatment compared to no-cover crop (NCC) treatment for both sampling period. K_s and bulk density values of first and second soil samples were not significantly affected by cover crop treatment. Longer term studies are needed to compare effects of cover crop and tillage on soil hydro-physical properties.

Keywords: bulk density, cover crop, K_s, soil pores, tillage, water content

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INTRODUCTION

Soil resilience is the ability of soil environment to sustain its important roles under internal and climatic tensions. Hence, a good soil physical quality is essential for resilient soils [8, 30]. Agricultural management practices may have direct and indirect impacts on soil hydro-physical properties and can affect soil structure. Tillage is one of the management practices has been performed to incorporate manures, fertilizers, and residuals into the soil, to prepare ground for seedling, and to control weeds. However, tilling the soil is disruptive and can promote high moisture loss rates, degradation of soil structure and depletion of soil nutrients and carbon stocks [20–22, 28]. It has been very widely accepted that no-tillage amends soil quality parameters and offers many agroecosystem services [9]. Soil hydro-physical properties that are agronomically important for bulk density, pore size distribution, water retention [23, 38, 42], and saturated hydraulic conductivity (K_s) [29, 31].

Perennial vegetative management has been shown to enhance soil quality by improving organic matter content, thus contributing positively to watershed restoration and water quality [44]. Cover crops (CCs) are commonly used in crop rotation to improve soil quality and fertility. Most of them are grown in periods when the field is left bare to help prime the soil for the next cash crops [45] by influencing soil hydro-physical properties such as bulk density, pore size distribution, and water content. Moreover, CCs increase water infiltration [22], moderate soil temperature and thermal properties [18], improve soil microbial activity, enhance nutrient recycling, protect soil from erosion, and suppress weeds [10, 34]. Several researchers studied with grass hedges, grass buffers, CCs and they found that these management practices had an improvement of soil hydro-physical properties [11, 12, 30, 32, 33, 36, 37]. Cover cropping practices have been reported a reduction in bulk density and increment in macroporosity values of soil [9, 17, 40]. Hairy vetch (*Visia villosa* Roth.) and rye (*Secale cereale* L.) crops decreased bulk density and penetration resistance and increased aggregate stability, total porosity, and water content of a silt loam soil by no-till management in a 5-year study [40]. As reported in a study [11] CC management improved water retention and K_s for the −2.5 kPa pressure after five years cover crop establishment. Likewise, CC improved macropores by 24% [19]

Table 1. Some soil physical and chemical properties of the study site

Soil depth, cm	Sand	Silt	Clay	pH	OM, %	CEC, meq 100 g^{-1}
	%					
0—10	11.25	60.00	28.75	5.05	3.08	16.70
10—20	11.66	49.16	39.16	5.26	2.63	18.36
20—30	12.50	39.16	48.33	5.26	2.33	24.36
30—40	11.25	47.50	41.25	5.76	1.56	21.56

OM: Organic matter, CEC: Cation exchange capacity

and water infiltration parameters as compared to no-cover crop (NCC) management [22].

Despite the current knowledge on the influence of tillage and CC management practices on soil hydro-physical properties, there are still gaps in understanding of the interaction effects of these management practices on soil properties. Thus, the aim of the current study was to assess the influences of CC on water retention, pore-size distributions, K_s, and bulk density values of a silt-loam soil before and after tillage management.

OBJECTS AND METHODS

Site Description

Chariton County Soil Health Farm is located within the central eastern Chariton County, Missouri, United States (39°50′ N and 92°72′ W). Site climatic conditions include hot and humid summers with cold and extended winters and the majority of annual precipitation occurring in spring and early summer. Grundy silt loam (fine, smectitic, mesic Aquertic Argiudolls) was the predominant soil series at the sites selected for the study. Initial soil properties were collected in 2012 before any activities and shown in Table 1. The study site had previously been under a corn (*Zea mays* L.) and soybean (*Glycine max.*) rotation with chemical fertilizers/pesticides with conventional tillage (disk-harrow, chisel plow) over 20 years. Initial CC planting occurred during the fall of 2012 under rotational planting of wheat (*Triticum* spp.), corn and soybean rotation. CCs were terminated using herbicides by ground spraying [39]. Treatment factors were tillage at two levels (no-tillage and conventional tillage) and CC at two levels (CC and NCC). Species planted included hairy vetch (*Vicia villosa* Roth.), red clover (*Trifolium pretense*), turnips (*Brassica rapa* L.), cereal rye (*Secale cereals* L.), buckwheat (*Fagopyrum esculentum*), winter peas (*Lathryrus hirsutus* L.), barley (*Hordeum vulgare* L.), triticale (*Triticale hexaploide* Lart.), radish (*Raphanus sativus* L. var. *longipinnatus*), and cowpeas (*Vigna unguiculata*).

Soil Sampling and Analysis

Undisturbed soil cores measuring 76.2 mm diameter by 76.2 mm long were collected using a sampler with aluminum rings in a grid sample design. First soil samples (2 treatments × 6 replicates × 2 depths = 24 cores) were collected from the 0—10 cm and 10—20 cm depths before tillage and cover crop termination (since they only affect 0 to 20 cm deep) during spring in 2017. Second soil samples (2 treatments × 6 replicates × 4 depths = 48 cores) were collected after tillage and cover crops termination from the 0—10 cm, 10—20 cm, 20—30 cm, 30—40 cm depths during summer in 2017. The second samples were taken from the lower depths (20—30 and 30—40 cm) to have measurements on these depths not affected by cover crops.

Two plastic caps and masking tape were used on each end of the sample to secure soil inside the cylinders. The cores were transported and stored in the cold room at 4°C until further processing. Cheesecloth was attached to the bottom of the soil core using rubber bands, and another empty core was attached to the top of the core for saturated hydraulic conductivity (K_s) measurement. Soils were saturated with water in tubs for at least 24 h before K_s and water retention were measured. The electrical conductivity of the water was 0.68 dS m^{-1}, and sodium absorption ratio was 2.34. The constant-head method was used for K_s determination and the falling head method was used on some samples with K_s values less than 1 mm h^{-1} [35]. For water retention measurements, the same soil samples were re-saturated at 0, −0.4, −1.0, −2.5, −5.0, −10.0, and −20.0 kPa pressures using Buchner funnels as described by [25]. Pore size distribution was computed from the water retention data using the capillary equation [14]. Four classes of pore sizes were used: macropores (>1000 μm), coarse mesopores (60 to 1000 μm), fine mesopores (10 to 60 μm), and micropores (<10 μm) [4]. Pore size and volume estimations were calculated by determining water content retained the following soil water pressures: 0.0 to −0.4 kPa for macropores, −0.4 to −5.0 kPa for coarse mesopores, −5.0 to −33 kPa for fine mesopores and −33 kPa for micropores. Total porosity was estimated by saturated sample water content at 0.0 kPa pressure. Soil samples were air-dried at 35°C until a constant weight. The air-dried subsamples were used for the next water retention measurements at higher pressures (−33, −100, and −1500 kPa) with pressure plates [14]. The soil bulk density measurements were performed using the air-dried weight

adjusted for oven-dried weight with a measured volumetric water content [16].

Statistical Analysis

Analysis of variance was conducted using Minitab statistical package with the general linear model procedure. Statistical differences were declared significant at the level of 0.05 using with Tukey's test of means.

RESULTS AND DISCUSSION

Bulk Density and Saturated Hydraulic Conductivity

Result of bulk density (BD) for the first soil samples collected before tillage and cover crop (CC) termination at two depths (0–10, 10–20 cm) are presented in Table 2. Soil BD values were not significantly affected by treatment and depth ($p < 0.05$). BD was found numerically lower 4.87% at the 0–10 cm depth compared to the 10–20 cm depth.

BD results for the second soil samples collected after tillage and CC termination at four depths (0–10, 10–20, 20–30, and 30–40 cm) are presented in Table 2. No significant differences in soil BD were observed by CC treatment as compared to no-cover crop (NCC) treatment ($p < 0.05$). The mean BD values were found significantly lower (1.33 g cm^{-3}) at the surface 0–10 cm and higher (1.50 g cm^{-3}) at the 10–20 cm depth. One possible reason for the higher BD values at 0–20 cm is that tillage can cause a compacted "plow pan" layer under the tilled depth. Similar to the current study findings, other scientists [11] reported that no differences were determined under CC treatment over the years. They also reported that the lowest soil BD values were at 0–10 cm soil depth. According to [27], soil bulk density values were lower only in the uppermost 10 cm depth under two-year old perennial crops. This was explained by the fact that the major part of the roots subjected to decomposition in the first two years was found in the uppermost soil layer.

Saturated hydraulic conductivity (K$_s$) can influence solute transport through soil and affect patterns of water infiltration and runoff since K$_s$ has an important role by controlling water movement in the soil layers. Therefore, K$_s$ greatly dependent upon pore size arrangement and continuity [3, 6, 19, 43]. K$_s$ results for the first soil samples collected before tillage and CC termination at two depths are presented in Table 2. Soil K$_s$ values were not significantly affected by treatment ($p < 0.05$). K$_s$ values were found numerically 104.7% higher under CC treatment as compared to NCC treatment. Some researchers were also determined that numerical differences on soil K$_s$ under CC, NCC, miscanthus and switchgrass treatments [10]. Many researchers have also evaluated the influence of different management practices on K$_s$ [3, 26, 32, 37, 46]. Results of K$_s$ for the second soil samples collected after

Table 2. Means and analysis of variance results of saturated hydraulic conductivity (K$_s$) and bulk density (BD) of soil by treatment and soil depth

First sampling	K$_s$, mm h^{-1}	BD, g cm^{-3}
Treatment means		
CC	198.53 a	1.28 ± 0.128a
NCC	96.96 a	1.25 ± 0.109a
Depth means		
0–10 cm	194.40 a	1.23 ± 0.086a
10–20 cm	101.09 a	1.29 ± 0.139a
Anova		
Treatment	0.197	0.496
Depth	0.234	0.208
Treatment depth	0.550	0.126
Second sampling		
Treatment means		
CC	8.17 a	1.38 ± 0.074a
NCC	32.20 a	1.41 ± 0.150a
Depth means		
0–10 cm	52.23 a	1.33 ± 0.117b
10–20 cm	20.31 a	1.50 ± 0.086a
20–30 cm	4.66 a	1.42 ± 0.091ab
30–40 cm	3.53 a	1.33 ± 0.090b
Anova		
Treatment	0.114	0.361
Depth	0.088	<0.001
Treatment depth	0.358	0.010

CC = Cover crop, NCC = No-cover crop. The ANOVA table presents significance levels among treatments and by depth for the measured parameters. Means with different letters represent a significant difference at the 0.05 probability level (± Standard deviation).

tillage and CC termination at four depths are shown in Table 2. According to these results, no significant treatment and depth effects were observed ($p < 0.05$). Numerically higher K$_s$ values (32.20 mm h^{-1}) were obtained from NCC treatment as compared with CC treatment.

Moreover, K$_s$ values of both soil samples were numerically greater at the 0–10 cm depth compared with lower depths. Similar findings were also reported that K$_s$ values were greater at the 0–10 cm (33.4 mm h^{-1}) and 10–20 cm (33.5 mm h^{-1}) than at the 20–30 and 30–40 cm depths [3]. It was probably because CC management can improve soil structure and reduce bulk density and increase the proportion of larger pores which can led to greater K$_s$ values at this depth.

Cover crop treatments did not significantly affect soil K$_s$ probably because of low densities and slow root establishment. Many researchers were reported that longer term studies are needed to improve soil hydraulic properties [2, 11, 37, 41]. Although not statistically different due to low cover crop density, K$_s$ values were numerically greater in first soil samples compared to

Table 3. Means and analysis of variance results of pore size distributions of soil by treatment and soil depth

	Total pores	Macropores (>1000 μm)	Coarse mesopores (60−1000 μm)	Fine mesopores (10−60 μm)	Micropores (<10 μm)
		$m^3\ m^{-3}$			
First sampling					
Treatment means					
CC	0.517 ± 0.015a	0.034 ± 0.012a	0.070 ± 0.017a	0.082 ± 0.017a	0.331 ± 0.021a
NCC	0.494 ± 0.048b	0.020 ± 0.016b	0.077 ± 0.029a	0.060 ± 0.022b	0.337 ± 0.020a
Depth means					
0−10 cm	0.526 ± 0.022a	0.032 ± 0.016a	0.085 ± 0.023a	0.083 ± 0.017a	0.327 ± 0.017a
10−20 cm	0.484 ± 0.037b	0.022 ± 0.013a	0.063 ± 0.019b	0.059 ± 0.020b	0.341 ± 0.022a
Anova					
Treatment	0.011	0.034	0.425	0.001	0.491
Depth	<0.001	0.118	0.018	<0.001	0.111
Treatment depth	<0.001	0.647	0.074	0.030	0.368
Second sampling					
Treatment means					
CC	0.498 ± 0.034a	0.032 ± 0.017a	0.054 ± 0.019a	0.052 ± 0.029a	0.360 ± 0.027a
NCC	0.419 ± 0.072b	0.015 ± 0.015b	0.047 ± 0.029a	0.040 ± 0.020a	0.317 ± 0.079b
Depth means					
0−10 cm	0.450 ± 0.070ab	0.024 ± 0.023a	0.067 ± 0.025a	0.048 ± 0.021ab	0.311 ± 0.065b
10−20 cm	0.434 ± 0.062b	0.029 ± 0.018a	0.039 ± 0.023b	0.031 ± 0.016b	0.334 ± 0.067ab
20−30 cm	0.455 ± 0.081ab	0.025 ± 0.019a	0.052 ± 0.020ab	0.055 ± 0.030a	0.323 ± 0.053b
30−40 cm	0.494 ± 0.050a	0.015 ± 0.009a	0.043 ± 0.025b	0.049 ± 0.028ab	0.386 ± 0.038a
Anova					
Treatment	<0.001	0.001	0.154	0.057	0.004
Depth	0.061	0.238	0.001	0.034	0.003
Treatment depth	0.553	0.634	<0.001	0.001	0.015

CC = Cover crop, NCC = No-cover crop. The ANOVA table presents significance levels among treatments and by depth for the measured parameters. Means with different letters represent a significant difference at the 0.05 probability level (± Standard deviation).

second soil samples. Higher K_s values were expected for the first soil samples since they were collected before tillage and CC termination. Numerically higher K_s results are indicative of the ability of CCs to improve macropores and water infiltration because of their root activities and these roots can improve soil structure and pore connectivity [40]. Similar higher K_s results were also found under no tillage when compared with tillage [7, 24]. It was reported that the burrows made by endogenic earthworms were responsible for greater K_s values under no tillage as compared to tillage [24]. On the other hand, other scientists suggested that no tillage decreased the volume fraction of the larger pores and increased the volume fraction of the smaller pores with higher pore connectivity [7].

Pore Size Distributions

Water infiltration and transporting into the soil is very important and essential for pore size distribution. Pore size distribution results for the first soil samples (before tillage and CC termination at two depths) are shown in Table 3. Total pores (0.517 m³ m⁻³), macrop-

ores (0.034 m³ m⁻³) and fine mesopores (0.082 m³ m⁻³) were significantly higher under CC treatment compared to NCC treatment. There was a significant depth effect on total pores, coarse mesopores and fine mesopores. Moreover, there were some significant interactions on total pores and fine mesopores between treatment and depth.

Results of pore size distributions for the second soil samples (after tillage and CC termination at four depths) are shown in Table 3. Total pores (0.498 m³ m⁻³), macropores (0.032 m³ m⁻³), and micropores (0.360 m³ m⁻³) were found significantly greater by CC treatment compared to NCC treatment. Significant interactions were observed for coarse mesopores, fine mesopores and micropores between treatment and depth ($p < 0.05$). Moreover, some significant depth effects were determined for all pore sizes analyzed, except macropores. Total pores (0.494 m³ m⁻³) and micropores (0.386 m³ m⁻³) were found significantly higher at 30−40 cm depth. The increment of micropores at this depth was probably because of increasing clay content. Likewise, [37] and [46] were evaluated that clay concentration of soil increased by depth which decreased
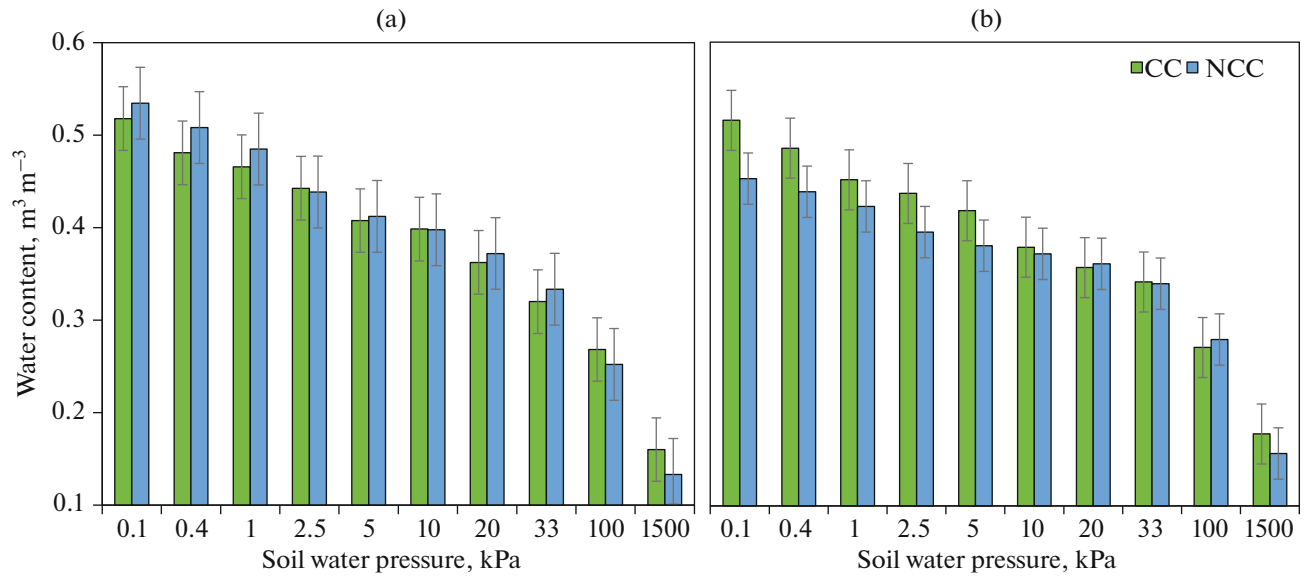
Fig. 1. Soil water retention curves for first soil samples under cover crop (CC) and no-cover crop (NCC) treatments at (a) 0−10 cm, and (b) 10−20 cm depths.

macropores and increased micropores. Generally, the claypan soils have slower water infiltration rates due to few numbers of macropore. Some researchers were used legume as CCs in a clay soil, and they reported that greater porosity and K_s values at 0−20 cm soil depth [15].

Furthermore, there were no significant treatment effects on coarse mesopores for both soil samples (Table 3). Total pores and macropores of both soil samples were affected by CC treatment. Total pores and macropores of second soil samples (after tillage and CC termination) were approximately 19% and 113% greater under CC treatment, respectively. This result is similar to the findings of [20] and [40]. CCs might increase soil pore spaces in two ways: through root growth and through the decomposition of organic materials. This can increase water movement within the vadose zone. It was reported that using leguminous cover crops decreased bulk density, improved soil aggregation, and porosity [13]. A ten-year study was performed on a sandy loam soil with no-till using radish and spring barley as CCs and determined greater macroporosity values as compared to NCC treatment with no-till [1].

Water Retention

Water retention of soil is greatly related to distribution of pore sizes [5]. Results of soil water retention measurement for the first soil samples (before tillage and CC termination at two depths) are presented in Table 4. These results show treatments, depths and treatment by depth interactions (treatment × depth)

had some significant effects on water content of soil at some water pressures. Water retention values were found statistically significant ($p < 0.05$) for the 0.0, −2.5, and −1500 kPa water pressures by CC treatment. Significantly higher water retention values were obtained from 0−10 cm depth compared with the 10−20 cm depth at 0.0, −0.4, −1, −2.5, −10, and −1500 kPa pressures. There were also some significant interactions between 0.0 and −5 kPa pressures between treatment and depth ($p < 0.05$). Moreover, no significant depth effects were observed at −5, −20, −33, and −100 kPa pressures.

Water retention results for the second soil samples (after tillage and CC termination at four depths) are presented in Table 4. Soil water retention values were significantly ($p < 0.05$) affected by CC treatment for all water pressures. Besides, there was a significant treatment and depth interaction on water retention at some soil water pressures (−20, −33, −100, and −1500 kPa). Additionally, there were significant depth effects on soil water retention for all water pressures. Significantly greater water content of second soil samples were generally obtained from 30−40 cm depth as compared to other depths. The reason was probably because bulk density of these soil samples for the 30−40 cm depth was lower than other depths due to higher clay content and micropores through subsoil horizons.

Differences among treatments for the first soil samples at 0−10 cm and 10−20 cm depths are given in Fig. 1. Water content values were greater at −2.5 kPa, −10 kPa, −100 kPa and −1500 kPa water pressures at 0−10 cm depth by CC treatment (Fig. 1a). Moreover, these values were also higher at 10−20 cm depth under

Table 4. Means and analysis of variance results of water content as a function of soil water pressure by treatment and soil depth

First sampling	Soil Water Pressure (kPa)									
	0.0	−0.4	−1.0	−2.5	−5.0	−10.0	−20.0	−33.0	−100	−1500
	$m^3\,m^{-3}$									
Treatment means										
CC	0.517 ± 0.015a	0.483 ± 0.020a	0.459 ± 0.021a	0.440 ± 0.020a	0.413 ± 0.020a	0.389 ± 0.024a	0.360 ± 0.024a	0.331 ± 0.021a	0.270 ± 0.028a	0.169 ± 0.012a
NCC	0.494 ± 0.048b	0.474 ± 0.038a	0.454 ± 0.035a	0.417 ± 0.028b	0.396 ± 0.026a	0.385 ± 0.025a	0.367 ± 0.026a	0.337 ± 0.020a	0.266 ± 0.024a	0.145 ± 0.015b
Depth means										
0–10 cm	0.526 ± 0.022a	0.495 ± 0.021a	0.475 ± 0.019a	0.441 ± 0.017a	0.410 ± 0.020a	0.398 ± 0.022a	0.367 ± 0.026a	0.327 ± 0.017a	0.260 ± 0.015a	0.146 ± 0.015b
10–20 cm	0.484 ± 0.037b	0.462 ± 0.030b	0.437 ± 0.023b	0.416 ± 0.029b	0.399 ± 0.028a	0.375 ± 0.022b	0.359 ± 0.024a	0.341 ± 0.022a	0.275 ± 0.032a	0.167 ± 0.014a
Anova										
Treatment	0.011	0.205	0.524	0.010	0.068	0.686	0.525	0.491	0.716	<0.001
Depth	<0.001	<0.001	<0.001	0.006	0.235	0.026	0.448	0.111	0.169	<0.001
Treatment depth	<0.001	<0.001	<0.001	0.031	0.024	0.747	0.794	0.368	0.252	0.433
Second sampling										
Treatment means										
CC	0.498 ± 0.034a	0.466 ± 0.038a	0.445 ± 0.038a	0.434 ± 0.038a	0.412 ± 0.030a	0.405 ± 0.028a	0.389 ± 0.027a	0.360 ± 0.028a	0.326 ± 0.029a	0.227 ± 0.048a
NCC	0.419 ± 0.072b	0.404 ± 0.071b	0.391 ± 0.070b	0.370 ± 0.071b	0.357 ± 0.073b	0.349 ± 0.075b	0.337 ± 0.077b	0.317 ± 0.079b	0.288 ± 0.076b	0.206 ± 0.075b
Depth means										
0–10 cm	0.450 ± 0.070ab	0.426 ± 0.068ab	0.406 ± 0.062b	0.378 ± 0.061b	0.359 ± 0.062b	0.348 ± 0.065b	0.333 ± 0.068b	0.311 ± 0.066b	0.262 ± 0.041c	0.154 ± 0.026d
10–20 cm	0.434 ± 0.062b	0.405 ± 0.056b	0.388 ± 0.056b	0.375 ± 0.058b	0.365 ± 0.059b	0.359 ± 0.062b	0.351 ± 0.064b	0.334 ± 0.067ab	0.306 ± 0.059b	0.189 ± 0.040c
20–30 cm	0.455 ± 0.081ab	0.431 ± 0.071ab	0.414 ± 0.065ab	0.398 ± 0.066b	0.378 ± 0.059b	0.372 ± 0.058b	0.354 ± 0.051b	0.323 ± 0.053b	0.294 ± 0.053bc	0.225 ± 0.029b
30–40 cm	0.494 ± 0.050a	0.478 ± 0.044a	0.465 ± 0.041a	0.456 ± 0.043a	0.436 ± 0.038a	0.427 ± 0.037a	0.416 ± 0.037a	0.386 ± 0.038a	0.366 ± 0.036a	0.299 ± 0.037a
Anova										
Treatment	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.001	0.018
Depth	0.061	0.010	0.005	0.001	0.001	0.001	0.001	0.003	<0.001	<0.001
Treatment depth	0.553	0.346	0.446	0.480	0.285	0.144	0.050	0.015	0.002	0.018

CC = Cover crop, NCC = No-cover crop. The ANOVA table presents significance levels among treatments and by depth for the measured parameters. Means with different letters represent a significant difference at the 0.05 probability level (± Standard deviation).
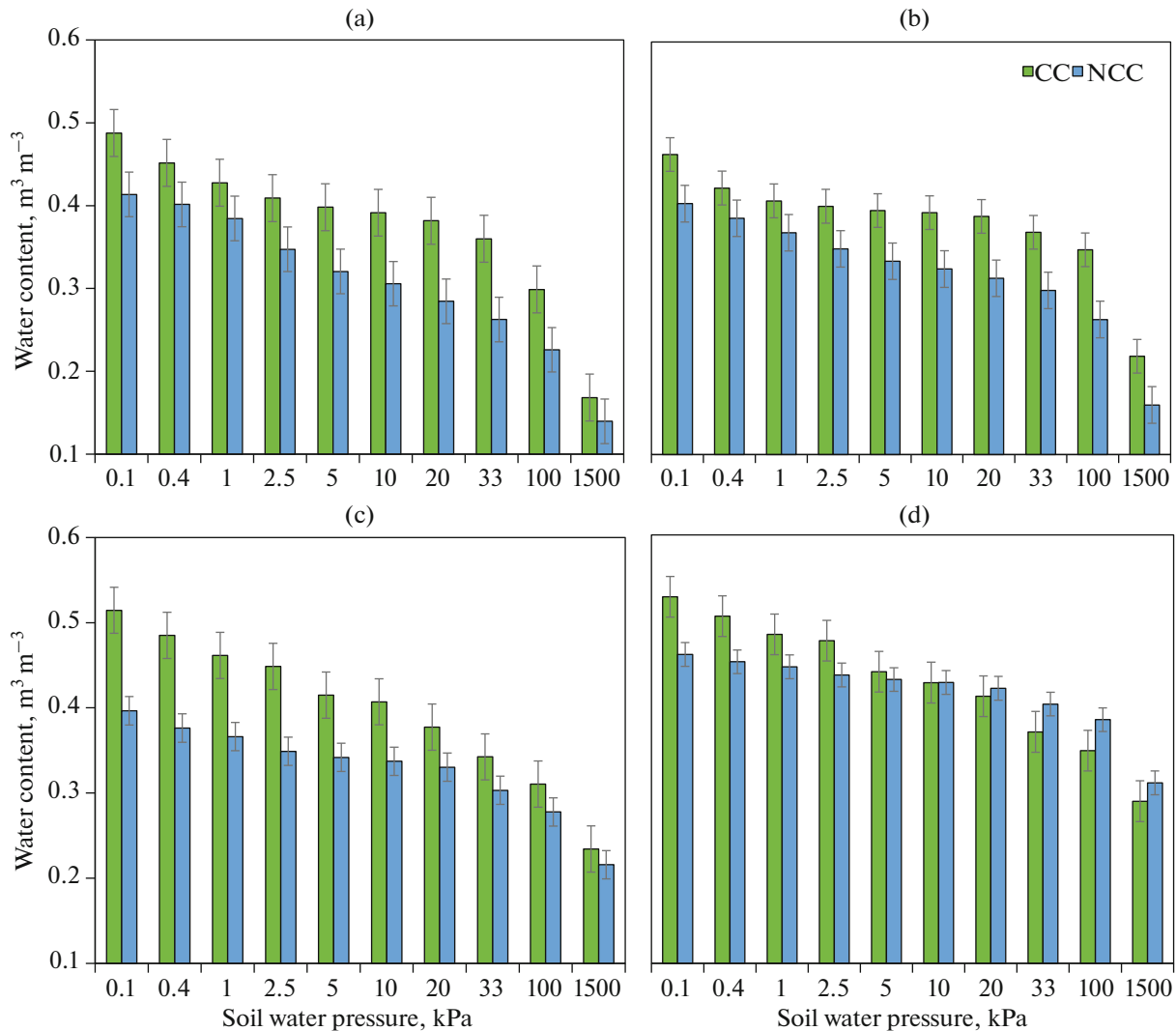
Fig. 2. Soil water retention curves for second soil samples under cover crop (CC) and no-cover crop (NCC). treatments at (a) 0–10 cm, (b) 10–20 cm, (c) 20–30 cm, and (d) 30–40 cm depths.

CC treatment for all pressures except −20 kPa, and −100 kPa pressures (Fig. 1b). Figure 2 shows that differences among treatments for the second soil samples at 0–10, 10–20, 20–30, and 30–40 cm depths. Water retention values were found higher for the all pressures at 0–10, 10–20 and 20–30 cm depths under CC treatment as compared to NCC treatment (Figs. 2a, 2b, 2c). This was probably due to increase pore spaces left behind by cover crops. Higher soil water content values were also obtained from 30–40 cm depth by CC treatment for −0.1, −0.4, −1, −2.5, and −5 kPa water pressures (Fig. 2d). Similarly, some researchers were reported that increases in water content of soil samples at the 30–40 cm depth as compared with other depths due to a claypan horizon [11, 37]. According to other researchers [9] CC treatments increased soil water content by 4%. Similar increments on soil water content values by CC treatments were also determined by [11, 15, 46].

CONCLUSIONS

This study was conducted to investigate the influence of cover crop management practices on the hydro-physical properties of the soil samples collected before and after tillage period. The greater positive effects of water content, pore size distribution, and K_s were observed in first soil samples collected before tillage and cover crop termination compared to second soil samples collected after tillage and cover crop termination. Overall, this study demonstrated that no significant differences were found on K_s of both soil samples by cover crop treatment and depth. Additionally, there were no significant treatment and depth effects on soil bulk density values for both soil sampling period. Total pores and macropores of both soil samples were significantly higher under cover crop treatment as compared with no-cover crop treatment. Especially total pores and macropores of second soil

samples (after tillage and cover crop termination) were found approximately 19% and 113% higher compared to first soil samples (before tillage and cover crop termination) by cover crop, respectively. Coarse mesopore values of both soil samples were not significantly affected by cover crop treatment. Changes in soil total pores and macropores are translated into increases in water retention properties by CC treatments. Soil water retention of first samples was significantly greater under cover crop treatment for the 0.0, −2.5, −1500 kPa water pressures and significantly affected by soil depth at all pressures (except −5, −20, −33, −100 kPa). In addition, water retention values of second soil samples were found significantly higher by cover crop and depth for all pressures. Generally higher water content values of second samples were determined from 30−40 cm depth for all pressures as compared with other depths because of claypan horizon.

The effects of these sustainable management practices on soil hydro-physical properties take time in order to become prevalent. Future, long-term cover crop studies are needed to compare soil hydro-physical properties by specific effects of cover crop and tillage.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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