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In situ water infiltration: Influence of cover crops after growth termination

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Abstract

Cover crops (CCs) are known to influence water infiltration just prior to termination, but their effects on water infiltration over time are less known. This study investigated the influence of CCs on in situ water infiltration just prior to CC termination (during April) and again 2 mo after CC termination (during June). The multi-species mixture of CCs used included hairy vetch (*Vicia villosa* Roth.), crimson clover (*Trifolium incarnatum* L.), winter wheat (*Triticum aestivum* L.), winter peas (*Lathyrus hirsutus* L.), oats (*Avena sativa* L.), triticale (*Triticale hexaploide* Lart.), barley (*Hordeum vulgare* L.), and flax (*Linum usitatissimum* L.). Infiltration rates were measured using double-ring infiltrometers during April and June. The physically based Parlange and Green-Ampt models were fitted to measured infiltration data. Cumulative infiltration was 52% higher in April and 68% higher in June under CC compared with no cover crop (NC) management. During April, the Parlange model–estimated saturated hydraulic conductivity parameter (K_{dr}) was 245% higher under CC compared with NC management. During the same sample period, the Green-Ampt–estimated K_{dr} parameter was 383% higher under CC compared with NC management. The higher sorptivity parameter and lower antecedent water content under CC compared with NC management during both measurement periods suggest that CCs can significantly improve water infiltration into the soil, and this effect can last for up to 2 mo after CC termination.

1 | INTRODUCTION

Water infiltration is important for predicting water distribution within the vadose zone after irrigation or precipitation (Rimon et al., 2007) and predicting the movement of contaminants to groundwater after surface spill (Soga et al., 2003). Agronomically, water infiltration is important for the critical zone recharge (Shanafield & Cook, 2014) and crop productivity (Bell et al., 2011). Therefore, water infiltration studies are important for improved crop productivity and environmental sustainability.

Several infiltration models have been developed to describe the process by which water displaces air in a porous material, including those proposed by Green and Ampt (1911) and Parlange et al. (1982). These physically based models

Abbreviations: CC, cover crop; NC, no cover crop; SOC, soil organic carbon.

predict infiltration rate and cumulative infiltration volume based on parameters like sorptivity (*S*) and saturated hydraulic conductivity (K_{dr}). The *S* parameter quantifies the effect of soil matric forces and is highly dependent upon the antecedent volumetric water content (θ) of the soil (Culligan et al., 2005). The K_{dr} parameter quantifies water movement under saturated conditions and can be indicative of the proportion of macropores and mesopores (Zaibon et al., 2017). As such, these parameters are influenced by soil management practices like the introduction of cover crops (CCs) into crop rotation cycles, which can influence antecedent θ and pore size distribution.

For several decades, CCs have been used to improve soil conditions prior to planting the subsequent staple/cash crop (Dabney et al., 2001; Haruna et al., 2020). As a result, the adoption of CCs has been increasing over the last decade. For example, the number of farms adopting CCs grew by 15% from 2012 to 2017 (USDA-NASS, 2017) due to improvements in soil health parameters and crop growth. Cover crops have been reported to improve soil organic carbon (SOC) by 12 (Sainju et al., 2002), 26 (Haruna et al., 2017), and 30% (Blanco-Canqui et al., 2011) in the top 30 cm of soil compared with no cover crop (NC) management. As a result, Sainju et al. (2002) reported a 7% decrease, Haruna et al. (2017) reported a 3% decrease, and Blanco-Canqui et al. (2011) reported a 4% decrease in soil bulk density (ρb) under CC compared with NC management. Further, Abdollahi et al. (2014) reported that the roots of CCs may create continuous biopores that drain rapidly under gravity, and this can reduce antecedent θ. This reduction in ρb and antecedent θ has been reported to increase water infiltration parameters and cumulative water infiltration (de Almeida et al., 2018; Franzleubbers, 2002; Matula, 2003). For example, Folorunsho et al. (1992) reported that bromegrass (*Bromus* spp.) and strawberry clover [*Trifolium fragiferum* L. ssp. Bonanni (C. Presl) Sojak.] CCs reduced surface soil crust strength by 38–41%, and this led to a 20–101% increase in cumulative infiltration relative to NC management.

Several studies have reported on the influence of CCs on soil water infiltration and infiltration parameters (e.g., Bilek, 2007; Haruna, Nkongolo, et al., 2018; Kasper et al., 2001; Nouri et al., 2019). However, these studies were conducted prior to CC termination. Currently, there is a need to understand the influence of CCs on soil water infiltration during the staple/cash crop growing season. As such, the current study investigated the influence of CCs on water infiltration parameters just prior to CC termination and again 2 mo after CC termination. It is hypothesized that, after several rainfall events, the benefits of CCs on water infiltration will reduce 2 mo after termination.

Core Ideas

- Cover crop reduced antecedent water content before and after termination.
- Parlange and Green-Ampt models provided good fits for measured infiltration data.
- Cover crop increased quasi-steady infiltration rate 2 mo after termination.
- Cover crop increased in situ measured saturated hydraulic conductivity.
- Cover crop management can improve water infiltration 2 mo after termination.

2 | MATERIALS AND METHODS

2.1 | Site description

This study was conducted at a field located in Murfreesboro, TN, USA. The soil was classified by the USDA as a Cumberland silt loam (fine, mixed, semiactive, thermic Rhodic Paleudalfs) with the following horizons: Ap (0–20 cm), B1 (20–36 cm), B21t (36–69 cm), B22t (69–102 cm), B23t (102–122 cm), and B24t (122–163 cm). Particle size distribution is shown in Table 1. The climate of the study area is Humid Subtropical (Köppen Climate Classification [Köppen, 1936]). The average 30-yr precipitation was 1,357 mm, with May (139 mm) and October (85 mm) recording the highest and lowest precipitation, respectively. The mean annual temperature over the last three decades was 14.6 ˚C, with the months of January (−3.7 ˚C) and August (32.3 ˚C) being the coldest and warmest, respectively. The mean precipitation during April of 2021 was 62 mm, and during June of 2021, the mean precipitation was 43 mm at the study site.

2.2 | Management description

The experimental design included three replicated plots in a completely randomized design, with two levels of CCs (CCs vs. NC). Management for the site was no-till. A suite of several CCs was used, including hairy vetch (*Vicia villosa* Roth.), crimson clover (*Trifolium incarnatum* L.), winter wheat (*Triticum aestivum* L.), winter peas (*Lathyrus hirsutus* L.), oats (*Avena sativa* L.), triticale (*Triticale hexaploide* Lart.), barley (*Hordeum vulgare* L.), and flax (*Linum usitatissimum* L.). These crops were chosen to simulate the

TABLE 1 Particle size distribution as a function of depth for the study site (Cumberland silt loam)

Depth	Silt	Sand	Clay
cm		%	
0–10	64.17	23.33	12.50
10–20	62.50	21.67	15.83
20–30	60.83	20.83	18.33

conventional practice for the region and have been used for about 5 yr on this field before the establishment of this study. The main grain crop (cash crop) grown was corn (*Zea mays* L.), planted in April using a 51-cm row planter and harvested in September in each growing season using a John Deere S680 combine harvester (Deere & Company).

Prior to the establishment of this study in 2020, the field was under 5 yr of CC management and over 15 yr of corn monoculture and no-till management. Each spring, the CCs were terminated. After the harvest of the corn in September 2020, the research plots were delineated. Each plot measured 20.1 m in length and 7.4 m in width. For this study, CCs were first overseeded and then drilled in using a John Deere 750 drill (Deere & Company) during October 2020 at the following total rates as recommended by the University of Tennessee Cooperative Extension: 5.6 kg ha^{-1} for hairy vetch, 5.9 kg ha^{-1} for crimson clover, 22.4 kg ha^{-1} for winter wheat, 14.6 kg ha^{-1} for winter peas, 29.1 kg ha^{-1} for oats, 22.4 kg ha^{-1} for triticale, 15.3 kg ha^{-1} for barley, and 50.4 kg ha^{-1} for flax. The CCs were allowed to grow during the winter months and were terminated on 14 Apr. 2021 using glyphosate [N-(phosphonomethyl) glycine]. Two passes of a 30-ft roller crimper were used a few hours after spraying the glyphosate to complete the termination of CCs. All plots were rainfed during this research.

2.3 | Soil sampling and analysis

Soil samples and infiltration measurements were conducted 7–9 d after an average of 41 mm rainfall. Soil samples were collected using a sampler with a cylindrical core measuring 5.5 cm inside diameter by 6.0 cm long from nontrafficked rows just before CCs were terminated (in April) and about 2 mo later (in June, when corn was growing) at depths of 0–6 and 6–12 cm. During each sampling period, a total of 12 soil samples were collected (2 treatments × 2 depths × 3 replicates). Soil samples were collected about 1.2 m away from the infiltration rings and also about 1.2 m from the constant head permeameter to avoid bypass flow. After the samples were collected, excess soil was removed using a soil test spatula, labeled, and placed in plastic bags. Samples were stored in a refrigerator at 4 ˚C until analysis. Additionally, penetration resistance (τ) was measured in each plot using a hand-driven cone penetrometer (Eijkelkamp) at 6- and 12-cm depths in each plot. A total of 12 τ measurements were made (2 depths × 2 treatments × 3 replicates). The τ results from cohesive forces between individual soil particles and frictional resistance met by the particles as they slide over one another, and it provides an indication of soil compaction.

Soil cores were removed from the refrigerator, they were taken from the plastic bags, and weighed. Cheesecloth was gently placed at the bottom of each core and secured by rubber bands. Soil cores were then placed in a tub and saturated for about 24 h by gently raising the water level. The electrical conductivity of the water was 0.3 dS m^{-1} at 20 ˚C. After saturation, the constant head method was used to evaluate saturated hydraulic conductivity (K_{lab}) (Reynolds & Elrick, 2002). If any soils had K_{lab} values <0.1 cm h^{-1}, the falling head method was used. After the K_{lab} measurement, ρb was determined using the core method (Grossman & Reinsch, 2002). Gravimetric water content was determined using the method of Haruna and Nkongolo (2015), and θ (cm^3 cm^{-3}) was determined from gravimetric water content using ρb. The soil was then ground and passed through a 2-mm sieve. Twenty grams of the <2 mm particles were used for soil texture determination using the pipette method (Gee & Or, 2002). Another 10 g of the <2 mm aggregates was used for SOC determination using the combustion method (Schulte & Hopkins, 1996).

2.4 | Infiltration measurement

Ponded infiltration was measured in each of the three replicates of CC and NC management during April (just before CC termination) and again during June. During the June measurement, some CC residues were visible on the soil surface in the CC plots. A total of six measurements (1 measurement × 2 treatments × 3 replicates) were made from nontrafficked midrow crop areas during each measurement period. Infiltration rates (falling head method) were measured using double ring infiltrometer units (Eijkelkamp). The double-ring data provide an in situ measure of surface infiltration, saturated hydraulic conductivity, and sorptivity. The outer ring measured 56 cm in diameter, and the inner ring measured 30 cm in diameter. Both rings had a length of 25 cm and wall thickness of 0.2 cm. The rings were driven vertically into the soil to a depth of 10 cm, and infiltration was conducted for 120 min. A Guelph permeameter (Kanwar et al., 1990) was used to measure in situ subsurface saturated hydraulic conductivity (K_{Guelph}) from 10-cm-deep holes about 1.8 m from the infiltration rings.

2.5 | Infiltration models

For a two-parameter model, the Green and Ampt (1911) (henceforth referred to as Green-Ampt) and the Parlange et al. (1982) (henceforth referred to as Parlange) models typically provide consistent fits with small confidence intervals (Clausnitzer et al., 1998). Therefore, these models were fitted to the measured infiltration data. Phillip (1957a) modified the Green-Ampt model for time (t) versus cumulative infiltration (I) (Equation 1).

$$t = \frac{I}{K_s} - \frac{\left[S^2 \ln\left(1 + \frac{2IK_s}{S^2}\right)\right]}{2K_s^2} \tag{1}$$

where t (T) is time (h), I (L) is the cumulative infiltration (mm), S (L T$^{-0.5}$) is the sorptivity (mm h$^{-0.5}$), and K_s (L T^{-1}) is the saturated hydraulic conductivity (mm h$^{-0.5}$).

The Parlange model was modified from Talsma and Parlange (1972) for t versus I as follows (Equation 2):

$$t = \frac{I}{K_s} - \frac{S^2\left[1 - \exp\left(-\frac{2IK_s}{S^2}\right)\right]}{2K_s^2} \tag{2}$$

The methods of Clothier and Scotter (2002) was used to estimate the S and K_s parameters for the Green-Ampt and Parlange models. The initial S parameter (at $t = 2$ min) was estimated by dividing the initial infiltration (at $t = 2$ min) by time $(t)^{0.5}$, and the initial K_s parameter was the steady infiltration rate (mm h^{-1}) (Haruna, Nkongolo, et al., 2018). Measured I versus t data were fit to the Green-Ampt and Parlange models using a nonlinear fitting procedure described by Haruna, Nkongolo, et al. (2018). From the errors (i.e., the difference between measured and predicted data) produced from each model, the RMSE was calculated according to Equation 3.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left[Z(\text{Xi}) - \hat{Z}(\text{Xi})\right]^2} \tag{3}$$

where N is the number of samples, Z(Xi) is the observed value, and $\hat{Z}$(Xi) is the predicted value.

To fit the models to measured infiltration data, the volume of water infiltrated was first determined. The volume of water infiltrated was determined by multiplying the volume of the inner ring by the difference in the elevation of the measuring float. The rate of water infiltration (R_{wi}) (mm h^{-1}) was calculated using Equation 4.

$$R_{wi} = \frac{D_1 - D_i}{t_1 - t_i} \tag{4}$$

where D_1 and t_1 are the depth and time, respectively, of infiltration at the next infiltration time; D_i is the depth of infiltration at the initial infiltration time; and t_i is the initial infiltration time. The quasi-steady infiltration rate (q_s) (mm h^{-1}) was determined when the slopes of the cumulative infiltration times were within 5% of each other (Arriaga et al., 2010).

The Guelph permeameter uses a well/auger-hole method for in situ saturated hydraulic conductivity measurement. This technique involves augering an unlined well into the vadose zone, ponding one or more constant heads of water in the well, and measuring the steady three-dimensional movement of water out of the well into the surrounding unsaturated soil. Using the ponded head and discharge data, estimates of in situ saturated hydraulic conductivity, K_{Guelph}, and sorptive number (α) can be obtained (Equation 5).

$$K_{\text{Guelph}} = [(0.0041) \times (R_C) \times (R_2)] - [(0.0054) \times (R_C) \times (R_1)] \tag{5}$$

where R_C is the combined reservoir constant (35.39 cm^2 for this study), and R_1 and R_2 are the steady state rate of flow at 5- and 10-cm ponding depths, respectively. The matric flux potential (Φ_m) was calculated using Equation 6.

$$\Phi_m = [(0.0572) \times (R_C) \times (R_1)] - [(0.0237) \times (R_C) \times (R_2)] \tag{6}$$

The α parameter was then calculated as a ratio of K_{Guelph} to ϕ_m. For this study, the well radius was 4 cm, and the well depth was 12 cm.

There are some distinctions in the saturated hydraulic conductivities and their notations in the current study. Laboratory-measured saturated hydraulic conductivity is denoted as K_{lab}, in situ measured saturated hydraulic conductivity is denoted as K_{Guelph}, and the model estimated saturated hydraulic conductivity from double ring infiltration measurement is denoted as K_{dr}.

2.6 | Statistical analysis

Analysis of variance was conducted on ρb, SOC, θ, τ, S, q_s, K_{lab}, K_{Guelph}, and K_{dr} using the general linear model in SAS version 9.4 (SAS Institute, 2013) for treatment and depth effects. Statistical differences were declared at $p \leq .05$.

3 | RESULTS

3.1 | SOC and soil physical properties

The means and SE for selected soil physical properties are shown in Table 2. Averaged over all treatments, SOC was

TABLE 2 Means with SE for soil organic C (SOC), soil bulk density (ρb), antecedent volumetric water content (θ), and penetration resistance (τ) during April and June

Treatment	SOC	April ρb	April θ	April τ	June ρb	June θ	June τ
	g kg^{-1}	g cm^{-3}	cm^3 cm^{-3}	MPa	g cm^{-3}	cm^3 cm^{-3}	MPa
CC	19.50 ± 0.42 a	1.18 ± 0.04 b	0.18 ± 0.02 b	0.66 ± 0.04 b	1.24 ± 0.02 b	0.20 ± 0.03 b	0.80 ± 0.02 b
NC	14.17 ± 0.36 b	1.29 ± 0.04 a	0.31 ± 0.05 a	0.82 ± 0.03 a	1.30 ± 0.03 a	0.31 ± 0.04 a	0.93 ± 0.04 a
Treatment × depth, cm							
CC 0–6	20.01 ± 1.20	1.09 ± 0.02	0.23 ± 0.02	0.61 ± 0.03	1.19 ± 0.01	0.27 ± 0.03	0.76 ± 0.02
NC 0–6	14.77 ± 0.80	1.24 ± 0.03	0.37 ± 0.03	0.78 ± 0.02	1.23 ± 0.01	0.39 ± 0.01	0.87 ± 0.03
CC 6–12	18.98 ± 1.40	1.28 ± 0.02	0.14 ± 0.01	0.70 ± 0.05	1.29 ± 0.01	0.14 ± 0.03	0.85 ± 0.02
NC 6–12	13.57 ± 1.14	1.35 ± 0.04	0.24 ± 0.08	0.86 ± 0.04	1.36 ± 0.01	0.23 ± 0.04	0.99 ± 0.06
ANOVA *p* > F							
Treatment	.002	.012	.028	.004	.002	.035	.003
Depth	.092	.003	.046	.055	<.001	.012	.007
Treatment × depth	.847	.259	.677	.879	.253	.775	.668

Note. CC, cover crop; NC, no cover crop. Soil organic C was only measured and reported during April. Mean comparisons were only made when *p* values for the main effects were ≤.05. Means with different letters within treatment means for a soil property are significantly different at the .05 probability level.

38% higher under CC compared with NC management but was not significantly different over sampled depths. Averaged over both depths during April and June, ρb was 9 and 5% higher, respectively, under NC compared with CC management. Averaged over both depths, antecedent θ during April was 72% higher under NC compared with CC management. During June, antecedent θ was 55% higher under NC compared with CC management. Further, when averaged over both depths, ρb under CC management was 5% higher during June compared with April, whereas ρb under NC management was 1% higher during June compared with April. Although antecedent θ under CC management was 11% higher during June compared with April, this soil property was similar under NC management during these periods. The treatment × depth interaction was not significant for either ρb or θ during April or June. The NC management had 24% higher τ values in April and 16% higher τ values in June compared with CC management. The τ under CC management was 21% higher during June compared with during April, whereas under NC management, τ was very similar during these measurement periods. The treatment × depth interaction did not significantly influence τ during April and June (Table 2).

3.2 | Ponded infiltration

After in situ infiltration measurements, two infiltration models (Parlange and Green-Ampt) were fitted to the measured cumulative infiltration data as a function of time. Typical replicates for the CC and NC managements are shown in Figure 1. Figures 1 and 2 illustrate the rapid increase, initially, in cumulative infiltration at early times and a steadier increase in cumulative infiltration near 2 h after initiating infiltration for both management practices and during each sampling period. In general, the models provided a good fit for the measured data, with r^2 ranging between .98 and .99 and RMSE ranging between 0.01 and 0.13 mm h^{-1} during both measurement periods. On average, cumulative infiltration after 2 h was 52% higher in April and 68% higher in June under CC compared with NC management. Under CC management, cumulative infiltration after 2 h was 36% higher in April compared with June. During the same measurement period, cumulative infiltration under NC management was 50% higher during April compared with June (Figure 2).

3.3 | Sorptivity and saturated hydraulic conductivity parameters

The sorptivity (S) and saturated hydraulic conductivity (K_{dr}) parameters estimated by the Parlange and Green-Ampt models during April and June are shown in Table 3. Although not significant for both models during the sampling periods, the S parameter was numerically higher under CC management compared with NC management. Similarly, during April, the K_{dr} parameter estimated by the Parlange model was 245% higher under CC compared with NC management. During the same period, the K_{dr} parameter estimated by the Green-Ampt model was 383% higher under CC management compared with NC management. During June, the K_{dr} parameter was numerically higher under the CC management compared with NC management. Compared with June, the Parlange model–estimated S parameter was 54% higher during April. Likewise, the S parameter estimated by the Green-Ampt model

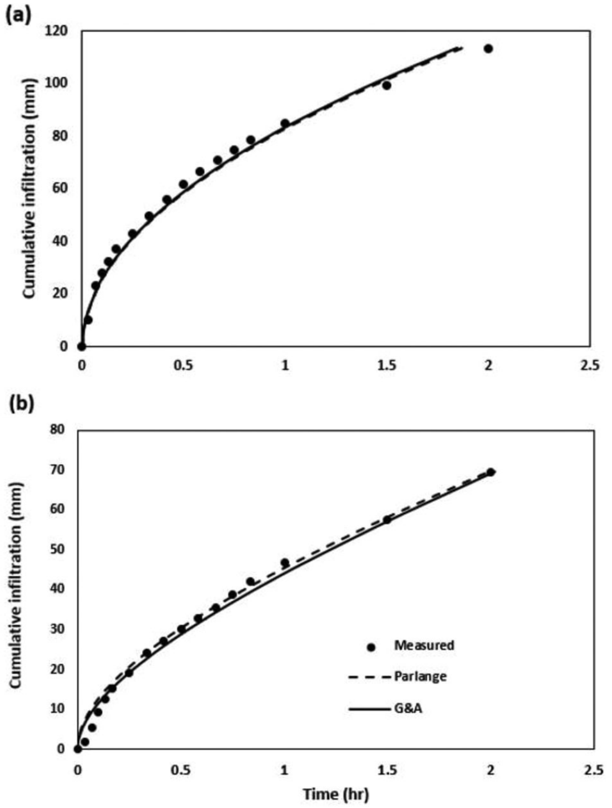

FIGURE 1 The Parlange and Green-Ampt (G&A) models fitted to measured infiltration data for typical replicate under (a) cover crop and (b) no cover crop treatments for April. The y-axis scale is different for both treatments

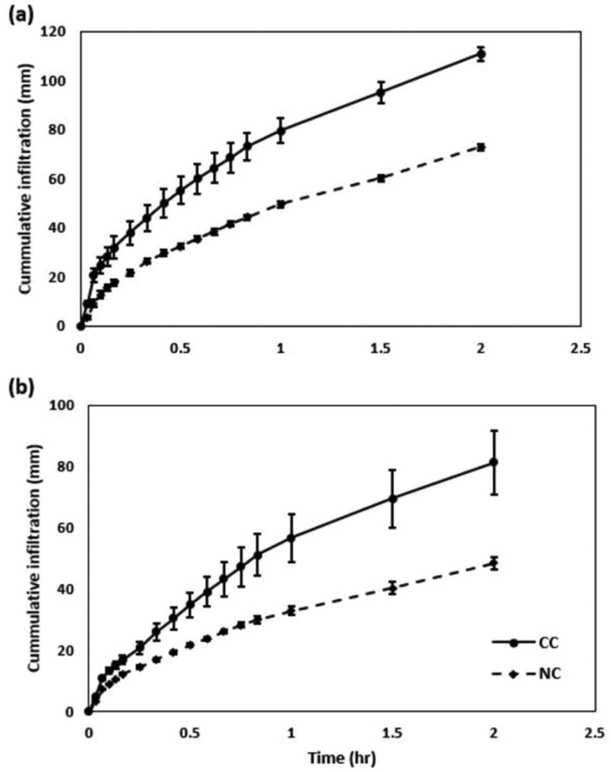

FIGURE 2 Measured ponded infiltration for typical replicates during (a) April and (b) June for cover crop (CC) and no cover crop (NC) managements. Bars represent SE. Values are averages of the replicates for each management. The y-axis scale is different for both measurement periods

TABLE 3 Geometric means for the sorptivity (S) and saturated hydraulic conductivity (K_{dr}) parameters estimated by the Parlange and Green-Ampt models in the cover crop (CC) and no cover crop (NC) treatments during April and June

Treatment	Apr.		June	
	S	K_{dr}	S	K_{dr}
	mm h$^{-0.5}$	mm h^{-1}	mm h$^{-0.5}$	mm h^{-1}
Parlange				
CC	69.20	15.64 a	44.81	18.27
NC	42.26	4.53 b	27.88	11.20
ANOVA $p > F$				
Treatment	.143	.049	.167	.369
Green-Ampt				
CC	67.09	17.66 a	39.94	17.97
NC	33.43	3.66 b	24.89	9.71
ANOVA $p > F$				
Treatment	.150	.009	.148	.090

Note. CC, cover crop; NC, no cover crop; Mean comparisons were only made when p values for the main effects were ≤.05. Within a model, treatment means with different letters for an infiltration parameter are significantly different at the .05 probability level.

was 70% higher during April compared with June. The K_{dr} parameter estimated by the Parlange and Green-Ampt models under CC management were 17 and 2%, respectively, higher in June compared with April (Table 3).

3.4 | Quasi-steady infiltration rate and field-measured saturated hydraulic conductivity

Figures 3 and 4 show the log-transformed q_s infiltration rate data (from measured cumulative infiltration) and the geometric means of K_{Guelph} measured in situ using a constant-head permeameter. During April and June, neither property was significantly different between CC and NC management. However, they were numerically higher under CC management compared with NC management.

To evaluate the consistency of the K_{Guelph} and the K_{lab}, a comparison was made between K_{Guelph} and K_{lab} measured during April (Figure 5). The K_{lab} data were measured on soil cores from 0 to 6 cm and from 6 to 12 cm, and the average of both depths was taken for each treatment. The correlation

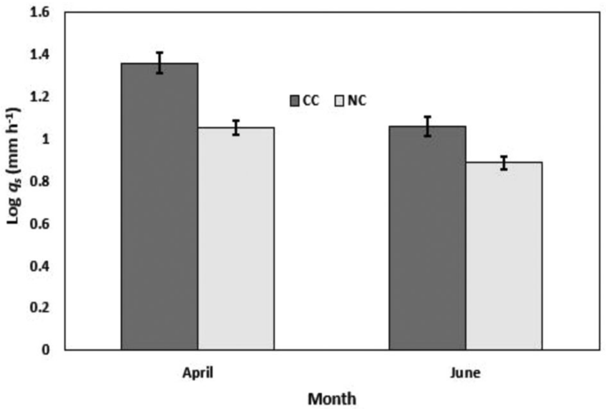

FIGURE 3 Log-transformed quasi-steady (q_s) infiltration rate under cover crop (CC) and no cover crop (NC) managements measured during April and June. Bars represent SE

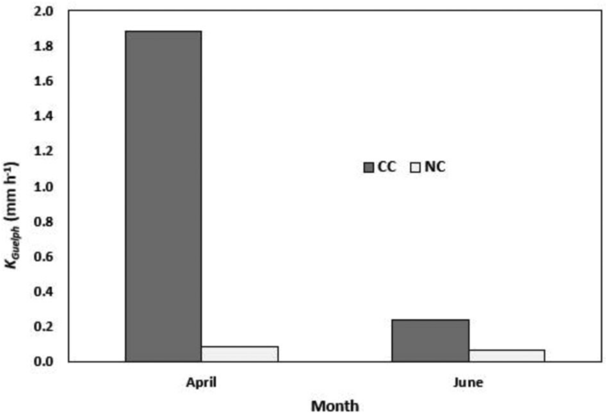

FIGURE 4 Geometric means of in situ measured saturated hydraulic conductivity (K_{Guelph}) under cover crop (CC) and no cover crop (NC) management during April and June

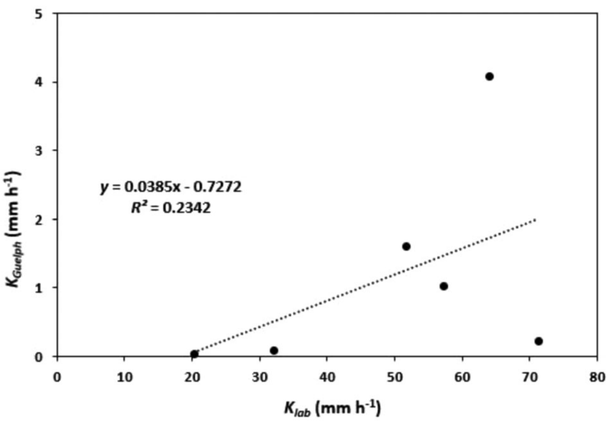

FIGURE 5 In situ measured saturated hydraulic conductivity (K_{Guelph}, April data) versus laboratory-measured saturated hydraulic conductivity (K_{lab}, April data)

coefficient for the regression between K_{Guelph} and K_{lab} was .24. The slope of the regression was found to be 0.04. The biggest and smallest difference between K_{Guelph} and K_{lab} occurred under CC and NC managements, respectively.

4 | DISCUSSION

4.1 | SOC and soil physical properties

Higher SOC values under CC compared with NC were attributed to the aboveground and belowground biomass as well as rhizosphere deposition of the various CCs (Kumar et al., 2018). Working on similar soils and climatic conditions, Haruna (2019) reported a 26% higher SOC under CC compared with NC at the 0-to-18-cm soil depth. The current study involved a multi-species mix of CCs compared with a single CC used in the study of Haruna (2019), and this root density and diversity in the current study could have led to the higher difference in SOC between these management systems. This suggests that a mix of several CC species may improve SOC within the soil over time, compared with the use of a single CC.

Because the roots of most CCs used in the current study are concentrated at the top 15 cm of the soil (Bodner et al., 2019; Yu et al., 2016), SOC was understandably similar between both sampled depths. Besides contributing to SOC, soil penetration of CC roots can also influence ρb (Haruna, 2019). Therefore, the lower ρb under CC management at both sampled depths may be partly attributed to the roots of the CCs noticed during the current study. The root growth and rhizosphere deposition of the belowground biomass can increase soil porosity, reduce ρb, and alleviate soil compaction (Landl et al., 2021). Further, due to the lower mass/volume ratio of SOC, higher SOC under CC management may have also resulted in the lower ρb values under CC management. The numerically higher ρb values during June compared with April under CC management at the 0-to-6-cm depth can be attributed to natural and rainfall-induced soil consolidation (Wilson et al., 2020). The gradual decomposition of CC roots after termination can favor soil consolidation.

Cover crops can influence θ in several ways. As a result of transpiration, living CCs can reduce antecedent θ, as shown in April. Further, as their roots decay, water rapidly drains under gravity from the macro and mesopores left behind (Cercioglu et al., 2018). Some of the θ will also evaporate faster from these pores (Or & Lehmann, 2019; Wang et al., 2021), and this probably led to lower antecedent θ during June compared with April.

The τ of most soils is highly dependent on static (particle size distribution) and dynamic (ρb and θ) properties, with researchers reporting a direct relationship between τ and ρb and an inverse relationship between τ and θ (at saturation) (Vaz et al., 2011; Whalley et al., 2007). Higher ρb and lower SOC values under NC management probably significantly increased the τ in the current study. Smith et al. (1997) reported a direct relationship between τ and θ at soil water pressures below saturation, which was similar to the results of the current study (soil samples and measurements were conducted 7–9 d after an average of 41 mm rainfall). Further, slightly higher clay content at the 6-to-12-cm depth may have been responsible for the numerically higher τ at this depth.

4.2 | Ponded infiltration

Since the RMSE helps aggregate the magnitude of errors in predictions for numerous data points into a single value of predictive power, the low RMSE values from the current study denote the accuracy of the Parlange and Green-Ampt models in predicting cumulative infiltration. As such, researchers can expect similar results if either model is chosen for future studies.

Soil organic C and living roots have been reported to improve soil structure and porosity (Fuentes et al., 2004). In fact, Haruna, Anderson, et al. (2018) reported that, at 2 wk after termination, macropores were 30% higher under cereal rye (*Secale cereal* L.) CC compared with NC management at the 0-to-20-cm depth interval. Further, Villamil et al. (2006) reported that CCs can significantly increase the volume of interconnected pores compared with NC. Soil organic C–induced improvements in soil structure, porosity, and pore connectivity (Cercioglu et al., 2018), and lower antecedent θ (Table 2) may have resulted in the higher cumulative water infiltration under CC compared with NC management during both sample periods.

Similar to ρb results, soil consolidation from rainfall (Wilson et al., 2020) probably resulted in the lower cumulative infiltration noticed during June compared with April for both management practices. However, the difference in cumulative infiltration during both measurement periods was higher under NC compared with CC management (Figure 2). This can be attributed to the exposure of the soils under NC management to raindrop effect due to lack of residue (Wilson et al., 2020). Therefore, after 2 mo, some of the CC residues on the soil surface (noticed during the June measurement) can reduce the kinetic energy of raindrops, protecting biopore integrity and increasing soil water infiltration.

The results also showed that, 2 mo after their termination, CCs still improved water infiltration probably due to biopore spaces left behind by decaying roots and microorganisms. This suggests that CC-induced increases in water infiltration can potentially reduce soil and nutrient runoff by increasing soil water recharge and storage.

4.3 | Sorptivity and saturated hydraulic conductivity parameters

When water is initially applied to a dry soil, the capillary potential of the soil matrix dominates the water infiltration process (gravitational processes will dominate over time). The S parameter quantifies the influence of capillarity on liquid movement into a porous material, and it is dependent on antecedent θ. Because S is related to water infiltration driven by capillary forces, it is inversely proportional to antecedent θ. The numerically higher S parameter values under CC compared with NC management may be a function of lower antecedent θ, which shows the ability of CCs to transpire water from the field, or it might be due to the interdependence between the S and K_{dr} parameters. This is further illustrated by the lower S parameter values estimated from both models during June compared with April. This near-surface water transpiration by CCs can be important in very wet growing seasons and can help lengthen the growing season of the cash crop. However, this might be detrimental in arid and semi-arid regions and also in regions where crop productivity is completely rain fed (Basche et al., 2016). However, despite the near-surface water transpiration by CCs, Daigh et al. (2014) and Duval et al. (2016) showed that differences in water content between CC and NC may not be significant enough to reduce cash crop productivity in humid continental and humid subtropical climates, respectively. This can be achieved through appropriate CC species selection and proper timing of CC termination.

The K_{dr} parameter estimates the movement of water in the soil under saturated conditions and is dependent on, among other factors, soil structure. Due to higher SOC, the K_{dr} parameter was significantly higher under CC management compared with NC management. Although not significant, this parameter was numerically higher under CC management compared with NC management 2 mo later. This suggests that the benefits of CCs on the K_{dr} parameter may persist for at least 2 mo after CC termination.

Stewart et al. (2013) showed that scaled S parameter and θ curves were similar throughout a range of initial soil moisture and across all soil types. However, results from the current study show some uncertainty in the calculated S and K_{dr} parameters. Although Table 3 shows that the differences in θ between treatments may be mostly due to K_{dr} values, this might have resulted from the K_{dr} overestimation (Figure 1a). This probable overestimation of the K_{dr} parameter would likely underestimate the effects of the S parameter, as denoted by the relatively large S parameter values. Conversely, Jacka et al. (2014) reported that differences in θ between treatments were mostly due to K_{dr} values rather than differences in S values.

4.4 | Quasi-steady infiltration rate and field-measured saturated hydraulic conductivity

Phillip (1957b) compared the q_s infiltration rate to the saturated hydraulic conductivity of the surface layer when infiltration takes place. Further, Amoozegar (2004) related the q_s infiltration rate to the point when the volume of water entering the soil at fixed time intervals becomes constant during water infiltration. More recently, Arriaga et al. (2010) assumed that the q_s infiltration rate is achieved when the slopes of the cumulative infiltration at two infiltration times are within 5% of each other. The higher q_s infiltration rate values under CC compared with NC management further illustrates the ability of CCs to enhance water infiltration by lowering ρb and antecedent θ. Results from the current study also show that the benefits of CCs on q_s infiltration rate can last up to 2 mo after CC termination. However, the q_s infiltration rate was lower during June compared with April; this shows that the benefits of CCs on water infiltration parameters reduce after their termination (Figure 3).

The K_{Guelph} denotes water movement within the soil under gravitational forces and is important in determining groundwater recharge. The higher K_{Guelph} suggests that CCs can improve soil water drainage and underground water recharge and storage, even 2 mo after termination. Since soil water availability can affect nutrient availability and the release patterns of control-release fertilizers (Verburg et al., 2021), higher K_{Guelph} induced by CCs could increase crop productivity.

The correlation between K_{Guelph} and K_{lab} implies that CCs can influence soil pore parameters and water transport within the soil. The slope of the regression showed very little agreement between in situ and laboratory measurements of water conductivity. This could be due to either heterogeneity of soils in the field (Salverda & Dane, 1993), the time required to reach steady flow during field measurement (Bagarello et al., 1999), or both. Since the K_{fs} was measured in 10-cm-deep holes (as compared with 6-cm cores used for the K_{sat} measurement), slight heterogeneity might have resulted in these differences. Further, water flow through the soils in situ is more likely to be dictated by large pores or cracks rather than by the smaller pores (Bagarello et al., 1999).

The K_{Guelph} value could be estimated as $0.67 \times K_{lab}$ (Rachman et al., 2004) and $0.4 \times K_{lab}$ (Haruna, Nkongolo, et al., 2018). In the current study, this coefficient can be estimated by $0.04 \times K_{lab}$, which is significantly lower than reported by previous authors. The reason for this difference could be that previous authors evaluated the correlation between laboratory-measured conductivity and model-estimated conductivity, whereas the current study evaluated the correlation between laboratory- and field-measured conductivities. This was similar to the results of Salverda and Dane (1993). Therefore, the current study better estimates the relationship between laboratory- and field-measured conductivity.

The current study shows that CC management improves soil properties and infiltration parameters for up to 2 mo after their termination. Although CCs were terminated in April, it usually requires more than 2 mo for their biomass to be completely broken down by microorganisms (Lynch et al., 2016) (CC biomass was visually present on the soil surface during June measurement). As a result, this biomass may have protected the integrity of soil structure and porosity under CC management compared with NC management (Cui & Holden, 2015). This may have resulted in the higher difference in cumulative infiltration between CC and NC management during June (68%) compared with April (52%). In view of the fact that increased water infiltration usually increases water storage (Xianqing et al., 2012), CC management may potentially improve nutrient transport and availability and the overall crop productivity. Due to the temporal variability in precipitation patterns and infiltration parameters, multi-year analysis is needed.

5 | SUMMARY AND CONCLUSIONS

Water infiltration was measured using double-ring infiltrometer and a Guelph permeameter in a farmer's field to evaluate the effects of CC management on infiltration parameters during April and June. The Parlange and Green-Ampt models provided good fits (RMSE between 0.01 and 0.13) for measured infiltration data. Significantly lower ρb (due to higher SOC and CC roots) and lower antecedent θ (probably due to water transpiration and evaporation) may have resulted in increased cumulative infiltration observed under CC compared with NC management during April and June. As a result, the S parameter was slightly higher under CC compared with NC management, and this can improve water infiltration under CC management. The higher q_s infiltration rate suggests that CC management can increase groundwater recharge and storage compared with NC management, and this benefit can last for at least 2 mo after CC termination. Conclusively, CC can improve crop productivity by increasing soil water infiltration; however, these benefits wane 2 mo after their termination.

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AUTHOR CONTRIBUTIONS

Samuel I. Haruna: Conceptualization; Formal analysis; Funding acquisition; Project administration; Writing – review editing. Robert C. Eichas: Writing – original draft. Olivia M. Peters: Formal analysis. Alaina C. Farmer: Investigation. Devin Q. Lackey: Investigation. Julia E. Nichols: Investigation. Wyatt H. Peterson: Methodology. Neil A. Slone: Writing – original draft.

CONFLICT OF INTEREST

Even though Samuel I. Haruna was an associate editor of the journal, he was blinded during the peer-review process. Therefore, the authors declare that there are no intellectual, commercial, or financial relationships that could be construed as a potential conflict of interest.

REFERENCES

Abdollahi, L., Munkholm, L. J., & Garbout, A. (2014). Tillage system and cover crop effects on soil quality: II. Pore characteristics. *Soil Science Society of America Journal*, *78*(1), 271–279. https://doi.org/10.2136/sssaj2013.07.0302

Amoozegar, A. (2004). Soil permeability and dispersion analysis. In R. D. Down & J. H. Lehr (Eds), *Environmental instrumentation and analysis handbook* (pp. 644–649). John Wiley and Sons.

Arriaga, F. J., Kornecki, T. S., Balkom, K. S., & Raper, R. L. (2010). A method for automating data collection from a double-ring infiltrometer under falling head conditions. *Soil Use and Management*, *26*, 61–67. https://doi.org/10.1111/j.1475-2743.2009.00249.x

Bagarello, V., Iovino, M., & Reynolds, W. D. (1999). Measuring hydraulic conductivity in a cracking clay soil using the Guelph permeameter. *Transactions of the ASAE*, *42*(4), 957.

Basche, A. D., Kasper, T. C., Archontolius, S. V., Jaynes, D. B., Sauer, T. J., Parkin, T. B., & Miguez, F. E. (2016). Soil water improvements with long-term use of a winter rye cover crop. *Agricultural Water Management*, *172*(1), 40–50. https://doi.org/10.1016/j.agwat.2016.04.006

Bell, L. W., Kirkegaard, J. A., Swan, A., Hunt, J. R., Huth, N. I., & Fettell, N. A. (2011). Impacts of soil damage by grazing livestock on crop productivity. *Soil and Tillage Research*, *113*(1), 19–29. https://doi.org/10.1016/j.still.2011.02.003

Bilek, M. (2007). *Winter annual rye cover crops in no-till grain crop rotations: Impacts on soil physical properties and organic matter* (Master's thesis, University of Maryland). https://drum.lib.umd.edu/handle/1903/7268

Blanco-Canqui, H., Mikha, M. M., Presley, D. R., & Claassen, M. M. (2011). Addition of cover crops enhances no-till potential for improving soil physical properties. *Soil Science Society of America Journal*, *75*(4), 1471–1478. https://doi.org/10.2136/sssaj2010.0430

Bodner, G., Loiskandl, W., Hartl, W., Erhart, E., & Sobotik, M. (2019). Characterization of cover crop rooting types from integration of rhisobox imaging and root atlas information. *Plants*, *8*, 514. https://doi.org/10.3390/plants8110514

Cercioglu, M., Anderson, S. H., Udawatta, R. P., & Haruna, S. I. (2018). Effects of cover crop and biofuel management on computed tomography-measured pore parameters. *Geoderma*, *319*, 80–88. https://doi.org/10.1016/j.geoderma.2018.01.005

Clausnitzer, V., Hopmans, J. W., & Starr, J. L. (1998). Parameter uncertainty analysis of common infiltration models. *Soil Science Society of America Journal*, *62*, 1477–1487. https://doi.org/10.2136/sssaj1998.03615995006200060002x

Clothier, B., & Scotter, D. (2002). Unsaturated water transmission parameters obtained from infiltration. In J. H. Dane & C. G. Topp (Eds.), *Methods of soil analysis: Part 4. Physical methods* (pp. 879–898). SSSA.

Cui, J., & Holden, N. M. (2015). The relationship between soil microbial activity and microbial biomass, soil structure and grassland management. *Soil and Tillage Research*, *146*, 32–38. https://doi.org/10.1016/j.still.2014.07.005

Culligan, P. J., Ivanov, V., & Germaine, J. T. (2005). Sorptivity and liquid infiltration into dry soil. *Advances in Water Resources*, *28*(10), 1010–1020. https://doi.org/10.1016/j.advwatres.2005.04.003

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis*, *32*, 1221–1250. https://doi.org/10.1081/CSS-100104110

Daigh, A. L., Helmers, M. J., Kladivko, E., Zhou, X., Goeken, R., Cavdini, J., Barker, D., & Sawyer, J. (2014). Soil water during the drought of 2012 as affected by rye cover crops in fields in Iowa and Indiana. *Journal of Soil and Water Conservation*, *69*, 564–573. https://doi.org/10.2489/jswc.69.6.564

de Almeida, W. S., Panachuki, E., de Oliveira, P. T. S., da Silva Menezes, R., Sobrinho, T. A., & de Carvalho, D. F. (2018). Effect of soil tillage and vegetal cover on soil water infiltration. *Soil and Tillage Research*, *175*, 130–138. https://doi.org/10.1016/j.still.2017.07.009

Duval, M. E., Galantini, J. A., Capurro, J. E., & Martinez, J. M. (2016). Winter cover crops in soybean monoculture: Effects on soil organic carbon and its fractions. *Soil and Tillage Research*, *161*, 95–105. https://doi.org/10.1016/j.still.2016.04.006

Folorunso, O. A., Rolston, D. E., Prichard, T., & Loui, D. T. (1992). Soil surface strength and infiltration rate as affected by winter cover crops. *Soil Technology*, *5*(3), 189–197. https://doi.org/10.1016/0933-3630(92)90021-R.

Franzluebbers, A. J. (2002). Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil and Tillage Research*, *66*(2), 197–205. https://doi.org/10.1016/S0167-1987(02)00027-2

Fuentes, J. P., Flury, M., & Bezdicek, D. F. (2004). Hydraulic properties in a silt loam soil under prairie, conventional till, and no-till. *Soil Science Society of America Journal*, *68*, 1679–1688. https://doi.org/10.2136/sssaj2004.1679

Gee, G. W., & Or, D. (2002). Particle-size analysis. In J. H. Dane & G. C. Topp (Eds.), *Methods of soil analysis: Part 4. Physical methods* (pp. 272–278). SSSA.

Green, W. H., & Ampt, G. A. (1911). Studies on soil physics, part 1: The flow of air and water through soils. *Journal of Agricultural Science*, *4*, 1–24.

Grossman, R. B., & Reinsch, T. G. (2002). Bulk density and linear extensibility. In J. H. Dane & G. C. Topp (Eds.), *Methods of soil analysis: Part 4. Physical methods* (pp. 201–228). SSSA. https://doi.org/10.2136/sssabookser5.4.c9

Haruna, S. I. (2019). Influence of winter wheat on soil thermal properties of a paleudalf. *International Agrophysics*, *33*, 389–395. https://doi.org/10.31545/intagr/110850

Haruna, S. I., Anderson, S. H., Nkongolo, N. V., Reinbott, T., & Zaibon, S. (2017). Soil thermal properties influenced by perennial biofuel and cover crop management. *Soil Science Society of America Journal*, *81*, 1147–1156. https://doi.org/10.2136/sssaj2016.10.0345

Haruna, S. I., Anderson, S. H., Nkongolo, N. V., & Zaibon, S. (2018). Soil hydraulic properties: Influence of tillage and cover crops. *Pedosphere*, *28*, 430–442. https://doi.org/10.1016/S1002-0160(17)60387-4

Haruna, S. I., Anderson, S. H., Udawatta, R. P., Gantzer, C. J., Phillips, N. C., Cui, S., & Gao, Y. (2020). Improving soil physical properties through the use of cover crops: A review. *Agrosystems, Geosciences & Environment*, *3*, e20105. https://doi.org/10.1002/agg2.20105

Haruna, S. I., & Nkongolo, N. V. (2015). Effects of tillage, rotation, and cover crop on the physical properties of a silt loam soil. *International Agrophysics*, *29*, 137–145. https://doi.org/10.1515/intag-2015-0030

Haruna, S. I., Nkongolo, N. V., Anderson, S. H., Eivazi, F., & Zaibon, S. (2018). In situ infiltration as influenced by cover crop and tillage management. *Journal of Soil and Water Conservation*, *73*, 164–172. https://doi.org/10.2489/jswc.73.2.164

Jacka, L., Pavlasek, J., Kuraz, V., & Pech, P. (2014). A comparison of three measuring methods for estimating the saturated hydraulic conductivity in the shallow subsurface layer of mountain podzols. *Geoderma*, *219–220*, 82–88. https://doi.org/10.1016/j.geoderma.2013.12.027

Kanwar, R. S., Rizvi, H. A., Ahmed, M., Horton, R., & Marley, S. J. (1990). Measurement of field saturated hydraulic conductivity by using Guelph and velocity permeameters. *Transactions of the ASAE*, *32*, 1885–1890.

Kaspar, T. C., Radke, J. K., & Laflen, J. M. (2001). Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. *Journal of Soil and Water Conservation*, *56*(2), 160–164.

Köppen, W. (1936). *Das geographische system der klimate*. Gebrüder Borntraeger.

Kumar, S., Meena, R. S., Lal, R., Yadav, G. S., Mitran, T., Meena, B. L., Dotaniya, M. L., & Ayman, E. S. (2018). Role of legumes in soil carbon sequestration. In R. S. Meena, A. Das, G. S. Yadav, & R. Lal (Eds.), *Legumes for soil health and sustainable management* (pp. 109–138). Springer.

Landl, M., Phalempin, M., Schluter, S., Vetterlein, D., Vanderborght, J., Kroener, E., & Schnepf, A. (2021). Modeling the impact of rhizosphere bulk density and mucilage gradients on root water uptake. *Frontiers in Agronomy*, *3*, 6. https://doi.org/10.3389/fagro.2021.622367

Lynch, M. J., Mulvaney, M. J., Hodges, S. C., Thompson, T. L., & Thomason, W. E. (2016). Decomposition, nitrogen and carbon mineralization from food and cover crop residues in the central plateau of Haiti. *Springerplus*, *5*, 1–9. https://doi.org/10.1186/s40064-016-2651-1

Matula, S. (2003). The influence of tillage treatments on water infiltration into soil profile. *Plant Soil and Environment*, *49*, 298–306.

Nouri, A., Lee, J., Yin, X., Tyler, D. D., & Saxton, A. M. (2019). Thirty-four years of no-tillage and cover crops improve soil quality and increase cotton yield in Alfisols, southeastern USA. *Geoderma*, *337*, 998–1008. https://doi.org/10.1016/j.geoderma.2018.10.016

Or, D., & Lehmann, P. (2019). Surface evaporative capacitance: How soil type and rainfall characteristics affect global-scale surface evaporation. *Water Resources Research*, *55*, 519–539. https://doi.org/10.1029/2018WR024050

Parlange, J. Y., Lisle, I., Braddock, R. D., & Smith, R. E. (1982). The three parameter infiltration equation. *Soil Science*, *133*, 337–341.

Phillip, J. R. (1957a). The theory of infiltration: 2. The profile of infinity. *Soil Science*, *83*, 435–448.

Phillip, J. R. (1957b). The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. *Soil Science*, *84*, 257–264.

Rachman, A., Anderson, S. H., Gantzer, C. J., & Thompson, A. L. (2004). Influence of stiff- stemmed grass hedge systems on infiltration. *Soil Science Society of America Journal*, *68*, 2000–2006. https://doi.org/10.2136/sssaj2004.2000

Reynolds, W. D., & Elrick, D. E. (2002). Constant head soil core (tank) method. In J. H. Dane & G. C. Topp (Eds.), *Methods of soil analysis: Part 4. Physical methods* (pp. 804–808). SSSA.

Rimon, Y., Dahan, O., Nativ, R., & Geyer, S. (2007). Water percolation through the deep vadose zone and groundwater recharge: Preliminary results based on a new vadose zone monitoring system. *Water Resources Research*, *43*, W05402. https://doi.org/10.1029/2006WR004855

Sainju, U. M., Singh, B. P., & Whitehead, W. F. (2002). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil and Tillage Research*, *63*, 167–179. https://doi.org/10.1016/S0167-1987(01)00244-6

Salverda, A. P., & Dane, J. H. (1993). An examination of the Guelph permeameter for measuring the soil's hydraulic properties. *Geoderma*, *57*(4), 405–421. https://doi.org/10.1016/0016-7061(93)90052-M

SAS Institute. (2013). *SAS user's guide*. SAS Institute Inc.

Schulte, E. E., & Hopkins, B. G. (1996). Estimation of soil organic matter by weight loss-on ignition. In F. R. Magdoff, M. R. Tabatabai, & E. A. Hanlon Jr. (Eds), *Soil organic matter: analysis and interpretation* (pp. 21–32). SSSA.

Shanafield, M., & Cook, P. G. (2014). Transmission losses, infiltration and groundwater recharge through ephemeral and intermittent streambeds: A review of applied methods. *Journal of Hydrology*, *511*, 518–529. https://doi.org/10.1016/j.jhydrol.2014.01.068

Smith, C. W., Johnston, M. A., & Lorentz, S. (1997). The effect of soil compaction and soil physical properties on the mechanical resistance of South African forestry soils. *Geoderma*, *78*, 93–111.

Soga, K., Kawabata, J., Kechavarzi, C., Coumoulos, H., & Waduge, W. A. P. (2003). Centrifuge modeling of nonaqueous phase liquid movement and entrapment in unsaturated layered soils. *Journal of Geotechnical and Geoenvironmental Engineering*, *129*, 173–182. https://doi.org/10.1061/(ASCE)1090-0241(2003)129:2(173)

Stewart, R. D., Rupp, D. E., Abou Najim, M. R., & Selker, J. S. (2013). Modelling effect of initial soil moisture on sorptivity and infiltration. *Water Resources Research*, *49*, 7037–7047. https://doi.org/10.1002/wrcr.20508

Talsma, T., & Parlange, J. Y. (1972). One-dimensional vertical infiltration. *Australian Journal of Soil Research*, *10*, 143–150.

USDA National Agricultural Statistics Service (USDA-NASS). (2017). *Quick stats database*. http://quickstats.nass.usda.gov

Vaz, C. M. P., Manieri, J. M., de Maria, I. C., & Tuller, M. (2011). Modelling and correction of soil penetration resistance for varying soil water content. *Geoderma*, *166*, 92–101. https://doi.org/10.1016/j.geoderma.2011.07.016

Verburg, K., Bristow, K. L., McLachlan, G. D., Muster, T. H., Poole, J. M., Mardel, J. I., Zhao, Z., Wittwer-Schmid, K., & Wong, T. F. (2021). Understanding soil water effects on nitrogen release from controlled-release fertilizers. *Soil Science Society of America Journal*, *85*, 59–72. https://doi.org/10.1002/saj2.20141

Villamil, M. B., Bollero, G. A., Darmody, R. G., Simmons, F. W., & Bullock, D. G. (2006). No-till corn/soybean systems including winter cover crops: Effects on soil properties. *Soil Science Society of America Journal*, *70*, 1936–1944. https://doi.org/10.2136/sssaj2005.0350

Wang, H., Jin, J., Cui, B., Si, B., Ma, X., & Wen, M. (2021). Evaporating water is different from bulk soil water in δ 2 H and δ 18 O and has implications for evaporation calculation. *Hydrology and Earth System Sciences*, *25*(10), 5399–5413. https://doi.org/10.5194/hess-25-5399-2021

Whalley, W. R., To, J., Kay, B. D., & Whitmore, A. P. (2007). Prediction of the penetrometer resistance of soils with models with few parameters. *Geoderma*, *137*, 370–377. https://doi.org/10.1016/j.geoderma.2006.08.029

Wilson, G. V., Zhang, T., Wells, R. R., & Liu, B. (2020). Consolidation effects on relationships among soil erosion properties and soil physical quality indicators. *Soil and Tillage Research*, *198*, 104550. https://doi.org/10.1016/j.still.2019.104550

Xianqing, H., Zhikuan, J., Qingfang, H., Honxia, S., Wei, W., Junfeng, N., & Boaping, Y. (2012). Effects of different rotational tillage patterns on soil structure, infiltration and water storage characteristics in dryland. *Transactions of the Chinese Society of Agricultural Engineering*, *28*, 85–94.

Yu, Y., Loiskandl, W., Kaul, H. K., Himmelbauer, M., Wei, W., Chen, L., & Bodner, G. (2016). Estimation of runoff mitigation by morphologically different cover crop root systems. *Journal of Hydrology*, *538*, 667–676. https://doi.org/10.1016/j.jhydrol.2016.04.060

Zaibon, S., Anderson, S. H., Thompson, A. L., Kitchen, N. R., Gantzer, C. J., & Haruna, S. I. (2017). Soil water infiltration affected by topsoil thickness in row crop and switchgrass production systems. *Geoderma*, *286*, 46–53. https://doi.org/10.1016/j.geoderma.2016.10.016

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