

# Crop management effects on water infiltration for claypan soils

W.K. Jung, N.R. Kitchen, S.H. Anderson, and E.J. Sadler

**ABSTRACT:** Plant water and nutrient use for claypan soils are restricted by an argillic horizon (clay content > 500 g kg<sup>-1</sup>) that typically occurs 20 to 40 cm (8 to 16 in) below the soil surface. Identifying water infiltration characteristics for claypan soils under different management provides crucial information needed to optimize crop management and estimate watershed hydrology. The objectives of the study were: 1) to evaluate the influence of long-term annual cropping system (ACS) and perennial cropping system management (PCS) [such as Conservation Reservation Program (CRP) and hay crop] on water infiltration, and 2) to examine relationships between apparent soil electrical conductivity (EC<sub>a</sub>) and other claypan soil properties with water infiltration parameters. The effects of the ACS and PCS management on water infiltration parameters were evaluated using ponded water infiltration measurements in the field. Water infiltration parameters were estimated using the Green-Ampt infiltration equation. Apparent profile soil electrical conductivity was obtained using an EM38 sensor. Analysis of variance and orthogonal contrasts were used to determine effects of management treatments on water infiltration parameters and associated soil properties. Soil organic carbon and aggregate stability were significantly ( $P < 0.05$ ) improved after 12 years of CRP management compared to 12 years of ACS management. Antecedent soil water content and EC<sub>a</sub> were lower and water infiltration was greater for PCS than for the ACS. For a hay crop treatment (PCS), water infiltration was greatly improved when compared to any ACS or other PCS management treatments. Antecedent soil water content and soil organic carbon were significantly correlated with the water infiltration parameters. Soil EC<sub>a</sub> was significantly correlated with infiltration-estimated saturated hydraulic conductivity (K<sub>s</sub>). This relationship may be useful for mapping spatially-variable water infiltration within fields. In summary, PCS contributed to improved water infiltration as well as to increased soil organic carbon and soil aggregate stability. Soil EC<sub>a</sub> may be useful for characterizing management influence on water infiltration without labor intensive sampling.

**Keywords:** Claypan soil, cropping system, Green-Ampt equation, soil electrical conductivity, water infiltration

**Understanding the characteristics of water movement through root zones may provide critical information to develop and implement improved management practices and refine estimates of watershed hydrology.** Water is one of the most important factors impacting crop yield and transport of nutrients and chemicals in the soil profile (Walter et al., 2000). Soil properties related to water infiltration, including hydraulic conductivity, soil organic matter, soil bulk density, soil water content, and soil texture, impact plant-available water stored in

the root zone, evaporation from the soil, and plant transpiration (Nielsen et al., 1996). Both natural soil variation and management factors, such as tillage, crop type, and crop management techniques, cause water infiltration differences (Jensen et al., 1987).

Tricker (1981) found that within-field soil variation impacted water infiltration less than soil management or vegetation type. Grassland areas had significantly higher water infiltration rates than wooded areas. The higher infiltration rate on grassland areas was associated with greater soil organic matter

from perennial plant residues, which promoted water absorption and reduced runoff. Rachman et al. (2004) examined the effects of stiff-stemmed switch grass (*Panicum virgatum* L.) hedges managed for 10 years on water infiltration and concluded that these grass hedges greatly enhanced water infiltration compared with conventional row crop management. Following 13 years of row-crop management on a claypan soil, only small changes were found in soil bulk density (D<sub>b</sub>), soil organic matter, soil-water retention, and saturated hydraulic conductivity among different tillage and crop treatments (Blanco-Canqui et al., 2004). In contrast, other studies have reported that management significantly affects saturated hydraulic conductivity, especially when comparing conventional tillage with no-till (Karlen et al., 1994; Lal, 1999).

In the United States, the CRP was initiated to reduce erosion by taking land out of grain crop production (Dicks, 1994). CRP has been widely accepted in the U.S. Midwest with many producers seeding and maintaining perennial grass. Management of CRP has resulted in large benefits to soil quality (Karlen et al., 1999) and water quality (Randall et al., 1997). Previous studies reported that maintaining CRP improved soil aggregate stability, soil organic carbon (soil organic carbon), and water infiltration (Huggins et al., 1997). Few studies have been conducted to evaluate water infiltration effects of CRP management for poorly-drained claypan soils of Major Land Resource Area 113 (NSSC, 1996).

Soil management practices have unique outcomes, largely because soil-to-soil differences have been caused by the cumulative effects of multiple natural factors involved in their formation, including climate, topography, parent material, biological activity, and time (Jenny, 1941). Claypan soil management practices are important in the U.S. Midwest

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**Table 1. Description of crop management systems treatments.**

Systems	Initiation	Tillage	Cropping	Annual fertilizer input	Yield goal
<b>Annual cropping system (ACS)</b>					
ACS1	1991	Mulch till	Soybean-corn rotation	Corn: N 190 kg ha <sup>-1</sup> Lime, P and K by soil test	Corn: 10079 kg ha <sup>-1</sup> Soybean: 2508 kg ha <sup>-1</sup>
ACS2	1991	No-till	Soybean-corn rotation	Corn: N 151 kg ha <sup>-1</sup> Lime, P and K by soil test	Corn: 8063 kg ha <sup>-1</sup> Soybean: 2508 kg ha <sup>-1</sup>
ACS3	1991	No-till since '96	Soybean-corn-wheat rotation Cover crop: hairy vetch ( <i>Vicia villosa</i> ) ('94 - '95) and red clover ('96 - '02)	Corn: N 151 kg ha <sup>-1</sup> Lime, P and K by soil test	Corn: 8735 kg ha <sup>-1</sup> Soybean: 2508 kg ha <sup>-1</sup> Wheat: 4031 kg ha <sup>-1</sup>
<b>Perennial cropping system (PCS)</b>					
PCSa	1991	No-till	CRP Orchard grass ( <i>Dactylis glomerata</i> L.), smooth brome grass ( <i>Bromus inermis</i> Leyss.), timothy ( <i>Phleum pratense</i> L.), tall fescue ( <i>Festuca arundinacea</i> ), alfalfa ( <i>Medicago sativa</i> ) ('91) hairy vetch, red clover, lespedeza, birdsfoot trefoil ( <i>Lotus corniculatus</i> ) ('92)	Lime, P and K by soil test	None
PCSb	2001	No-till	Legume and warm season grass CRP Big bluestem ( <i>Andropogon gerardii</i> ), Indian grass ( <i>Sorghastrum nutans</i> ), tall dropseed, little blue stem ( <i>Andropogon scoparius</i> ), lespedeza, Ladino clover	Lime, P and K by soil test	None
PCSc	2001	No-till	Hay crop Cool season grass: Canadian wildrye, Virginia wildrye ( <i>Elymus virginicus</i> ) Warm season grass: big bluestem, eastern gamma grass ( <i>Tripsacum dactyloides</i> ), Indian grass, Ladino clover	N 90 kg ha <sup>-1</sup> Lime, P and K by soil test	Hay: 8960 kg ha <sup>-1</sup> Harvest 2-3 times per year

because these soils are highly sensitive to soil degradation from processes such as runoff and erosion (Nikiforoff and Drosdoff, 1943; Kitchen et al., 1998). The central claypan soil region occupies about 4 million ha (10 million ac) in Missouri and Illinois. Claypan soils are poorly drained because of a restrictive high-clay subsoil layer (argillic horizon). The claypan creates a unique hydrology, controlled by slow water flow in the matrix of the restrictive high-clay layer. Clay content in the argillic horizon is generally greater than 500 g kg<sup>-1</sup> and is comprised of smectitic (high shrink-swell) clay minerals. Kitchen et al. (1999) examined topsoil depth (or depth to the argillic horizon) of a typical claypan field and found that topsoil depths ranged from 20 cm (8 in) on sideslopes to over 100 cm (39 in) on footslopes. Severe erosion can result in the claypan being exposed at the soil surface.

Limited research has been conducted to concurrently evaluate the impact of annual cropping system (ACS) and perennial cropping system (PCS) management including CRP, on hydraulic characteristics for claypan soils. Identifying water infiltration characteristics as affected by crop management can provide crucial information to help optimize both crop productivity and efficiency of

water and nutrient use for these soils. Further, modeling of runoff from claypan soil watersheds can be refined with better estimates of how management affects water infiltration. Additionally, research is needed to evaluate the relationships between claypan soil quality properties and water infiltration properties. Because of costs associated with sampling and laboratory analysis, interest is high for finding innovative methods for quantifying soil hydraulic properties using sensors. As an example a sensor technology commonly used for assessing soil variation is apparent profile electrical conductivity (EC<sub>a</sub>). Soil EC<sub>a</sub> can depend on various soil properties, including soil water content, soil salinity, CEC (Rhoades et al., 1999; Corwin and Lesch, 2005), soil particle size distribution (Sudduth et al., 2003), topsoil depth (Doolittle et al., 1994), and management practices (Johnson et al., 2003). Little has been done to relate soil EC<sub>a</sub> to hydraulic properties of claypan soils.

The objectives of the study were: 1) to evaluate the influence of long-term ACS and PCS on water infiltration, and 2) to develop relationships between soil EC<sub>a</sub> and other claypan soil properties with water infiltration parameters. The parallel hypotheses were

that soil infiltration rates under perennial forages (e.g., PCS) would be higher than with grain cropping systems, and that soil EC<sub>a</sub> and other soil properties would be related to infiltration rates.

## Materials and Methods

**Study site.** The research was conducted at a site located 3 km (1.9 mi) north of Centralia, Missouri (39°13'48"N, 92°07'00"W). Predominant soil series are Adco (fine, smectitic, mesic Vertic Albaqualfs) and Mexico (fine, smectitic, mesic Aeric Vertic Epiaqualfs). These soils are very deep, somewhat poorly drained, and very slowly permeable, formed in loess or loess and pedisegment. They occur on uplands and have slopes of zero to three percent. Surface soil texture ranges from silt loam to silty clay loam. The subsoil claypan horizons are silty clay loam, silty clay, or clay and commonly contain as much as 500 to 650 g kg<sup>-1</sup> of clay content with smectitic clay being predominant. The mean annual temperature is 12°C (54°F), and the mean annual precipitation is 1004 mm (40 in) (USDA-NRCS, 1995).

**Experimental design and soil sampling.** Three grain ACSs and a CRP system were established in a randomized complete block



design in the spring of 1991 on plots on a catena (slope zero to two percent) of soil and landscape positions (Ward et al., 1994). For this study, sampling and measurements were conducted on the summit landscape position. A modified CRP system and a hay crop system were initiated in 2001 by splitting the former CRP plots into three PCS treatments (Table 1). ACS plots were 0.35 ha (190 m × 18.3 m) (0.84 ac; 623 ft × 60 ft) and PCS plots were 0.13 ha (190 m × 6 m) (0.28 ac; 623 ft × 20 ft).

The experiment was conducted with three ACSs and three PCS systems with three replications (Table 1). ACS was a mulch tillage (i.e., crop residues are generally left on the surface after tillage operations) corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] rotation system. Mulch tillage consisted of fall or early spring chisel plowing and field cultivation both before and after herbicide application for seedbed preparation and herbicide incorporation. ACS was a no-till corn-soybean rotation system. ACS was a no-till corn-soybean-wheat (*Triticum aestivum* L.) rotation system with a red clover (*Trifolium pretense*) (1996 to 2002) cover crop following wheat. Weed management for the ACS system was adaptive, meaning scouting of weed species and population dictated herbicide type, rate, and timing. PCSa, established in 1991, was primarily tall fescue intermixed with a small amount of legumes [Ladino clover (*Trifolium repens*) and Lespedeza (*Lespedeza striata*)]. Other species that were planted in 1991 did not survive longer than two or three years (Table 1). PCSb was managed with legumes and warm-season grasses. PCSc was a hay crop system intensively managed with a legume and both cool-season and warm-season grasses. The hay was harvested two or three times per year. PCSb and PCSc were initiated in the spring of 2001 by dividing the former PCSa plots into smaller experimental units. Additional details of these systems are presented in Table 1.

**Soil sampling and analysis.** Soil samples for soil organic carbon and aggregate stability determination were obtained from the 0 to 7.5 cm (0 to 3 in) soil depth in November 2002. ACS plots had been cropped with soybean in 2002. Three 5.5 cm (2.2 in) diameter cores were taken and combined at each sampling site. Samples were air dried and ground to pass a 2-mm sieve. Soil organic carbon was determined by the dry combustion method (LECO, St. Joseph, Michigan;

insignificant or no carbonate C was assumed for these soils). For water aggregate stability determination, air-dried samples were gently crumbled by hand and sieved to retain the 1- to 2-mm aggregates. These aggregates were stored at 4°C (39°F) until tested for stability using a wet sieving technique (Kemper and Rosenau, 1986). Apparent profile soil electrical conductivity (EC<sub>a</sub>) was obtained using the EM38 sensor (Geonics Limited, 1998) in both the shallow (0 to 7.5 cm; EC<sub>a-shallow</sub>) (0 to 3 in) horizontal mode and the deep (0 to 150 cm; EC<sub>a-deep</sub>) (0 to 59 in) vertical mode as described by Doolittle et al. (1994) at each soil sample location in November 2002. Readings were obtained by manually placing the EM38 at the soil surface.

**Infiltration measurements and analysis.** Infiltration rates were measured in late June and early July 2004 using a 25 cm (10 in) single-ring infiltrometer following Bouwer's (1986) method. We chose this sampling date because it represented a time when all management systems had a growing crop. Soil samples [(top 15 cm (6 in) depth)] were taken at the same time for gravimetric soil water determination. For the infiltration measurements, a steel ring was driven 15 cm (6 in) into the soil and plant residues were left intact. A positive head of 50 mm (20 in) was maintained inside the ring using a Mariotte system. Tests were conducted from 170 to 320 minutes. Specifics of infiltrometer operation and methods are described in Rachman et al. (2004).

The Green and Ampt (1911) infiltration equation was modified by Philip (1957) for time (*t*) vs. cumulative infiltration (*I*), as follows:

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

where,

- t* (h) = time,
- I* = the cumulative infiltration (mm),
- S* = the sorptivity (mm hr<sup>-0.5</sup>), and
- K<sub>s</sub>* = the saturated hydraulic conductivity (mm hr<sup>-1</sup>). For estimating the *S* and *K<sub>s</sub>* parameters, the method proposed by Clothier et al. (2002) was used. A method for estimating field saturated hydraulic conductivity (*K<sub>f</sub>*) as

suggested by Reynolds et al. (2002) was used to calculate *K<sub>f</sub>*. It assumes one-dimensional water flow in the infiltration ring, and uses the following equation:

$$K_f = \frac{q_s}{\left( \frac{H}{C_1 d + C_2 d} \right) + \left[ \frac{1}{[\alpha^*(C_1 d + C_2 d)]} \right] + 1} \quad (2)$$

where,

- K<sub>f</sub>* = the field-saturated hydraulic conductivity (mm hr<sup>-1</sup>),
- q<sub>s</sub>* = the quasi-steady infiltration rate (mm hr<sup>-1</sup>),
- a* = the radius of the infiltration ring (mm),
- H* = the hydraulic head of ponded water in the ring (mm),
- d* = the depth of ring insertion into the soil (mm),
- C<sub>1</sub>* and *C<sub>2</sub>* = are dimensionless quasi-empirical constants (*C<sub>1</sub>* = 0.993 and *C<sub>2</sub>* = 0.578 for this infiltrometer), and
- α\** = the soil macroscopic capillary length, assumed to be equal to 0.012 mm<sup>-1</sup> (Reynolds et al., 2002).

**Statistical analysis.** Analysis of variance (ANOVA) was performed to identify cropping system effects on water infiltration parameters and the impact of soil properties on them. The GLM procedure in the SAS program (SAS Institute, 1989) was used to determine orthogonal contrast effects for cropping system management treatments. Since PCSb and PCSc were split out of PCSa plots, these treatments could not be randomly assigned to experimental units within each block. They were randomly assigned within the plot that was originally a PCSa treatment. Based on advice from a consulting University of Missouri statistician, this unique treatment arrangement necessitated five different types of ANOVA for comparing cropping systems. One, for comparing ACS to PCS, PCS treatments were averaged together before the ANOVA. Two, to compare within ACS treatments and with PCSa, the PCSb and PCSc treatments were removed before the ANOVA. This analysis followed the original 1991 design. Three, to compare ACS treatments with PCSb, the PCSa and



**Table 2. Mean and standard error ( $\pm$ ) values and ANOVA probabilities of soil properties\* that relate to water infiltration for annual cropping system (ACS) and perennial cropping system (PCS) treatments.**

Crop management system		System	Antecedent soil water — (kg kg <sup>-1</sup> ) —	SOC — (g kg <sup>-1</sup> ) —	Aggregate stability — (%) —	EC <sub>a-shallow</sub> — (mS m <sup>-1</sup> ) —	EC <sub>a-deep</sub>
		Mean $\pm$ SE					
Annual cropping system (ACS)		ACS1	0.150 $\pm$ 0.003	12 $\pm$ 0.7	20 $\pm$ 1.1	57 $\pm$ 3	75 $\pm$ 2
		ACS2	0.169 $\pm$ 0.009	11 $\pm$ 0.6	21 $\pm$ 2.5	55 $\pm$ 2	74 $\pm$ 1
		ACS3	0.165 $\pm$ 0.015	13 $\pm$ 1.0	32 $\pm$ 3.5	55 $\pm$ 2	73 $\pm$ 2
Perennial cropping system (PCS)		PCSa	0.115 $\pm$ 0.003	16 $\pm$ 1.7	50 $\pm$ 9.5	39 $\pm$ 2	54 $\pm$ 3
		PCSB	0.125 $\pm$ 0.011	16 $\pm$ 0.0	38 $\pm$ 5.4	43 $\pm$ 3	61 $\pm$ 5
		PCSc	0.107 $\pm$ 0.008	17 $\pm$ 1.2	39 $\pm$ 3.1	46 $\pm$ 5	62 $\pm$ 7
ANOVA Type <sup>†</sup>	Comparison		ANOVA P-value				
1	ACS vs. PCS		0.002	0.001	<0.001	0.001	0.001
2	ACS1 vs. (ACS2 and ACS3)		0.19	0.79	0.28	0.50	0.75
2	ACS2 vs. ACS3		0.77	0.20	0.11	0.99	0.66
2	ACS vs. PCSa		0.005	0.01	0.002	<0.001	0.003
3	ACS vs. PCSb		0.03	0.002	0.003	0.003	0.02
4	ACS vs. PCSc		0.004	0.002	0.002	0.03	0.05
5	PCSa vs. PCSb		0.27	0.99	0.29	0.13	0.06
5	PCSa vs. PCSc		0.72	0.62	0.35	0.04	0.05

\* SOC = soil organic carbon; EC<sub>a-shallow</sub> = shallow apparent soil electrical conductivity; EC<sub>a-deep</sub> = deep apparent soil electrical conductivity.

<sup>†</sup> 1 = ANOVA with individual ACS treatments and PCS treatments averaged; 2 = ANOVA with ACS 1-3 and PCSa; 3 = ANOVA with ACS 1-3 and PCSb; 4 = ANOVA with ACS 1-3 and PCSc; 5 = PCS treatments only.

PCSc treatments were removed before ANOVA. Four, to compare ACS treatments with PCSc, the PCSa and PCSb treatments were removed before ANOVA. And five, to compare within PCS treatments, all ACS treatments were removed. While not ideal, this procedure minimized bias associated with not having complete randomization of all treatments. Pearson correlation analysis and regression was also employed to evaluate relationships among water infiltration parameters, soil properties, and soil EC<sub>a</sub>. Reported mean values include associated standard error to the mean.

## Results and Discussion

**Soil and EC<sub>a</sub> characteristics related to water infiltration.** Mean values of soil properties and soil EC<sub>a</sub> for all management systems are summarized along with ANOVA results (Table 2). The listed soil properties were selected for their potential relationship with infiltration parameters since they were considered critical measurements in other studies (Nielsen et al., 1996; Huggins et al., 1997).

Antecedent soil water content was found to be significantly higher ( $P = 0.002$ ) for ACS than for PCS management. However, no significant differences were found for this property among ACS and PCS treatments. The means for the antecedent soil water con-

tent for the ACS and PCS treatments were 0.161 $\pm$ 0.009 kg kg<sup>-1</sup> and 0.115 $\pm$ 0.007 kg kg<sup>-1</sup>, respectively. Since plants for the PCS treatments are perennial, they begin to grow and transpire water earlier in the spring compared to annuals for the ACS treatments. We attributed the lower soil water content to this effect. While not measured, field observations suggested total biomass was much greater on the PCS than on ACS treatments. This should also contribute to enhanced plant water uptake and transpiration.

Soil organic carbon was significantly higher ( $P = 0.001$ ) for PCS than for ACS management, however there were no significant differences among ACS or PCS treatments. Average values of soil organic carbon for PCS (16.3 $\pm$ 1.0 g kg<sup>-1</sup>) were 36 percent greater than those for ACS (12.0 $\pm$ 0.8 g kg<sup>-1</sup>). As expected from what others have found (McConnel and Quinn, 1988; Gebhart et al., 1994), 12 years of PCS management greatly contributed to soil organic carbon accumulation. Likewise, aggregate stability was significantly higher ( $P < 0.001$ ) for PCS than for ACS management. Aggregate stability for PCS (42.3 $\pm$ 6 percent) was greater than values for ACS (24.3 $\pm$ 2.4 percent). It is not surprising that aggregate stability was higher in the continuous perennial plant systems. For survival, these systems annually store C below

ground, facilitating soil aggregation (Huggins et al., 1997). This along with other factors described earlier contribute to improved aggregate stability for PCS management.

Both shallow and deep EC<sub>a</sub> readings were found to be higher for the ACS than for PCS management ( $P = 0.001$ ). However, no differences were found among ACS or among PCS treatments. Soil EC<sub>a</sub> is impacted by many different soil properties including topsoil depth, clay content, and soil water content (Doolittle et al., 1994; Geonics Limited, 1998; Jung et al., 2005). For claypan soils, claypan depth and soil moisture predominate (Sudduth et al., 2003). Therefore in this study since all measurement sites were on the same landscape position and soil type, differences in EC<sub>a</sub> were likely caused by differences in soil water content at the time of measurement. Soil water use by the different management systems likely created profile differences in soil water [not just in the surface 0 to 7.5 cm (0 to 3.0 in)], which could easily explain differences in soil EC<sub>a</sub> response. So in this situation, soil EC<sub>a</sub> could be used as a surrogate measure for profile water differences on similar summit soils.

**Water infiltration parameters.** Typical examples of cumulative water infiltration curves for the ACS and PCS treatments as a function of time are shown in Figure 1.



Coefficients of determination for the fitted models ranged from 0.62 to 0.98 (averaged 0.87) for experimental areas. Generally, the infiltration rate was higher during the first 30 min and then decreased. Infiltration rates after two to three hours were generally slow, as expected for this claypan soil. The cumulative infiltration in the PCSc was higher than in all of the other cropping systems.

The ANOVA for  $q_s$ ,  $K_{fs}$ , and the  $K_s$  and  $S$  parameters for the Green and Ampt model are shown in Table 3.  $K_s$  was significantly different ( $P = 0.004$ ) when contrasting the ACS and PCS treatments, with the mean of  $K_s$  for ACS ( $6.0 \pm 1.9 \text{ mm hr}^{-1}$ ;  $0.24 \pm 0.07 \text{ in hr}^{-1}$ ) significantly lower than that of PCS ( $13.5 \pm 3.5 \text{ mm hr}^{-1}$ ;  $0.53 \pm 0.14 \text{ in hr}^{-1}$ ). However, there were no differences among individual ACS treatments.

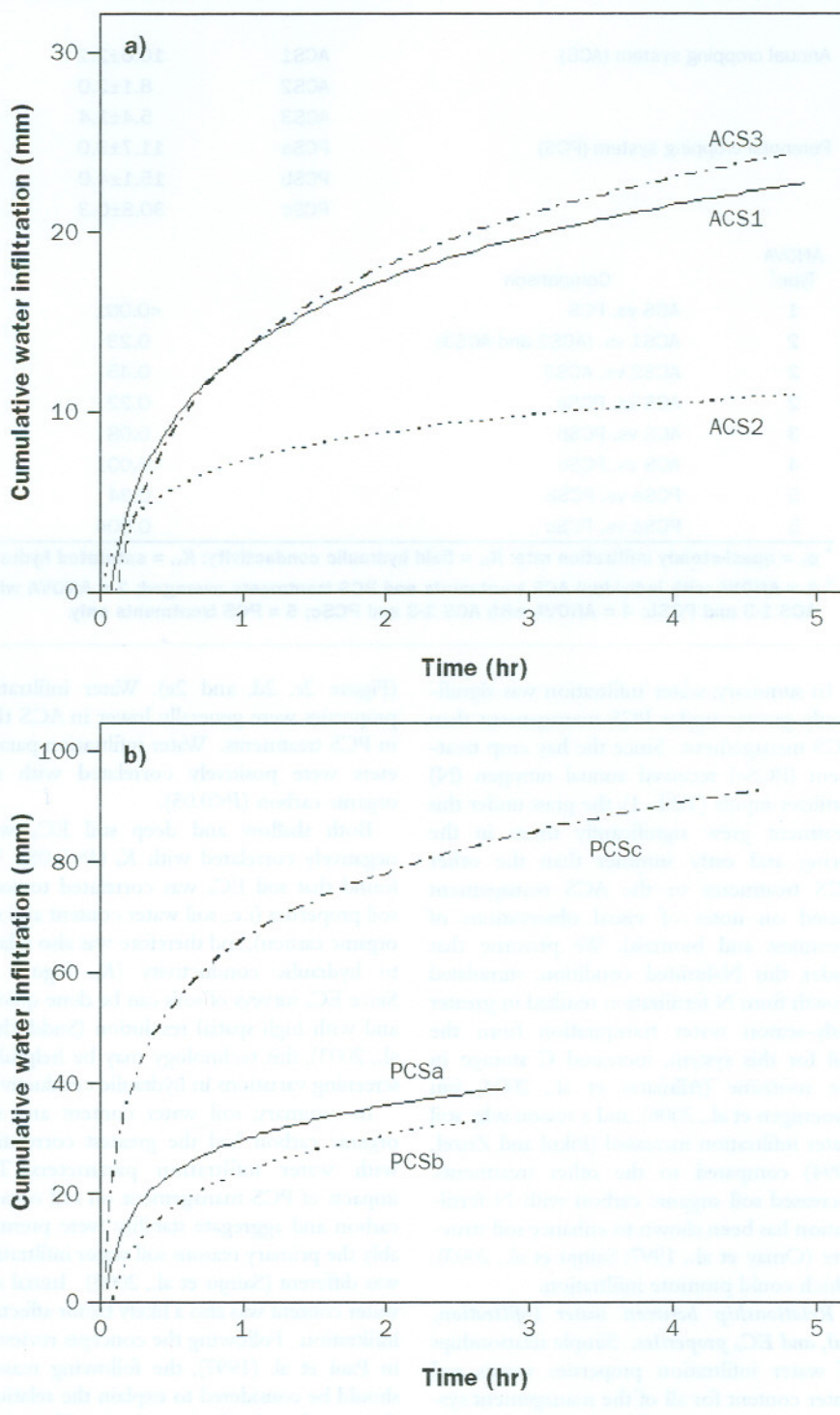
$S$  was found to be different between ACS and PCS ( $P < 0.001$ ). The mean of  $S$  was lower for the ACS ( $5.3 \pm 0.9 \text{ mm hr}^{-0.5}$ ;  $0.21 \pm 0.04 \text{ in hr}^{-0.5}$ ) compared to the PCS ( $12.3 \pm 2.2 \text{ mm hr}^{-0.5}$ ;  $0.48 \pm 0.09 \text{ in hr}^{-0.5}$ ). No differences occurred among the ACS treatments. The mean of  $S$  was significantly higher for the hay treatment PCSc than for PCSa. Since  $S$  is highly related to surface soil conditions such as antecedent soil water content, we feel differences in this parameter among treatments were partly due to differences in water content. While not statistically different, average soil water content in PCSc was lower than the other PCS treatments, an effect likely the result of greater plant biomass production for the hay crop relative to the other management systems.

Differences in  $K_{fs}$  and  $q_s$  as affected by management practices were found to be similar (Table 3). The mean of  $K_{fs}$  for ACS ( $5.5 \pm 1.3 \text{ mm hr}^{-1}$ ;  $0.22 \pm 0.05 \text{ in hr}^{-1}$ ) was significantly lower than that of PCS ( $13.2 \pm 1.7 \text{ mm hr}^{-1}$ ;  $0.52 \pm 0.07 \text{ in hr}^{-1}$ ).  $K_{fs}$  in PCSc was significantly higher than in PCSa.  $K_{fs}$  of PCSb was similar to PCSa. The mean of  $q_s$  for ACS ( $8.0 \pm 1.9 \text{ mm hr}^{-1}$ ;  $0.32 \pm 0.07 \text{ in hr}^{-1}$ ) was significantly lower than that of PCS ( $19.2 \pm 2.4 \text{ mm hr}^{-1}$ ).  $q_s$  for PCSc ( $30.8 \pm 0.3 \text{ mm hr}^{-1}$ ;  $1.21 \pm 0.01 \text{ in hr}^{-1}$ ) was significantly higher than for PCSa ( $11.7 \pm 3.0 \text{ mm hr}^{-1}$ ;  $0.46 \pm 0.12 \text{ in hr}^{-1}$ ).

We found that water infiltration for the claypan soil was significantly lower than what other research reported for other soil types. In a soybean-corn rotation,  $K_s$  was  $24.7 \text{ mm hr}^{-1}$  ( $0.97 \text{ in hr}^{-1}$ ) for a silt loam soil (Mollisols) in Iowa (Rachman et al., 2004).

**Figure 1**

Cumulative water infiltration characteristics for a) annual cropping system (ACS) and b) perennial cropping system (PCS) treatments. (See Table 1 for detailed description of specific ACS and PCS management treatments.)



This is four times greater than claypan soil's  $K_s$  for ACS ( $6.0 \text{ mm hr}^{-1}$ ;  $0.24 \text{ in hr}^{-1}$ ). In addition,  $K_s$  was six times greater after 10 years of grass hedge ( $153 \text{ mm hr}^{-1}$ ;  $6.03 \text{ in}$

$\text{hr}^{-1}$ ) than for ACS from the same study. We conclude that water infiltration in the claypan soil was highly restricted because of the high clay content argillic horizon.



**Table 3. Statistical significance of difference in water infiltration properties\* for all management systems.**

Management system	Treatment	$q_s$	$K_{fs}$	Green & Ampt model	
				$K_s$	S
			(mm hr <sup>-1</sup> )		– (mm hr <sup>-0.5</sup> ) –
			<b>Mean ± SE</b>		
Annual cropping system (ACS)	ACS1	10.6±2.2	7.3±1.5	7.7±2.2	6.8±0.7
	ACS2	8.1±2.0	5.5±1.4	5.4±2.1	6.0±1.5
	ACS3	5.4±1.4	3.7±1.0	5.0±1.5	3.0±0.6
Perennial cropping system (PCS)	PCSa	11.7±3.0	8.1±2.1	8.3±1.9	9.0±3.2
	PC Sb	15.1±4.0	10.4±2.7	15.3±4.3	4.3±0.3
	PC Sc	30.8±0.3	21.2±0.2	17.0±4.4	23.7±2.9
ANOVA Type†	Comparison			ANOVA Pvalue	
1	ACS vs. PCS	<0.001	<0.001	0.004	<0.001
2	ACS1 vs. (ACS2 and ACS3)	0.23	0.23	0.36	0.36
2	ACS2 vs. ACS3	0.45	0.44	0.89	0.31
2	ACS vs. PCSa	0.22	0.21	0.36	0.14
3	ACS vs. PC Sb	0.08	0.08	0.04	0.33
4	ACS vs. PC Sc	<0.001	<0.001	0.02	<0.001
5	PCSa vs. PC Sb	0.34	0.34	0.19	0.29
5	PCSa vs. PC Sc	0.004	0.003	0.12	0.02

\*  $q_s$  = quasi-steady infiltration rate;  $K_{fs}$  = field hydraulic conductivity;  $K_s$  = saturated hydraulic conductivity; S = sorptivity.

† 1 = ANOVA with individual ACS treatments and PCS treatments averaged; 2 = ANOVA with ACS 1-3 and PCSa; 3 = ANOVA with ACS 1-3 and PC Sb; 4 = ANOVA with ACS 1-3 and PC Sc; 5 = PCS treatments only.

In summary, water infiltration was significantly greater under PCS management than ACS management. Since the hay crop treatment (PC Sc) received annual nitrogen (N) fertilizer inputs (Table 1), the grass under this treatment grew significantly more in the spring and early summer than the other PCS treatments or the ACS management (based on notes of visual observations of greenness and biomass). We presume that under this N-limited condition, stimulated growth from N fertilization resulted in greater early-season water transpiration from the soil for this system, increased C storage in the rootzone (Allmaras et al., 2004; van Groenigen et al., 2006), and a reason why soil water infiltration increased (Pikul and Zuzel, 1994) compared to the other treatments. Increased soil organic carbon with N fertilization has been shown to enhance soil structure (Omay et al., 1997; Sainju et al., 2003), which could promote infiltration.

**Relationship between water infiltration, soil, and  $EC_e$  properties.** Simple relationships of water infiltration properties versus soil water content for all of the management systems were plotted in Figure 2 with correlation coefficients in Table 4. Water infiltration properties (i.e.,  $K_s$ , and S) were positively correlated with  $q_s$  (Figures 2a, and 2b) and negatively correlated with soil water content

(Figure 2c, 2d, and 2e). Water infiltration properties were generally lower in ACS than in PCS treatments. Water infiltration parameters were positively correlated with soil organic carbon ( $P < 0.05$ ).

Both shallow and deep soil  $EC_e$  were negatively correlated with  $K_s$  ( $P < 0.05$ ). We found that soil  $EC_e$  was correlated to some soil properties (i.e., soil water content and soil organic carbon), and therefore was also related to hydraulic conductivity ( $K_s$ , Figure 3). Since  $EC_e$  surveys of soils can be done quickly and with high spatial resolution (Sudduth et al., 2003), this technology may be helpful in screening variations in hydraulic conductivity.

In summary, soil water content and soil organic carbon had the greatest correlation with water infiltration parameters. The impacts of PCS management on soil organic carbon and aggregate stability were presumably the primary reasons soil water infiltration was different (Sainju et al., 2003). Initial soil water content was also a likely factor affecting infiltration. Following the concepts reviewed in Paul et al. (1997), the following reasons should be considered to explain the relationships we found: 1) more plant residues were returned to the soil with PCS management, 2) more resistance to erosion processes occurred under PCS management because the surface cover was much higher during

and after the growing season, 3) the perennial seasonal grass with PCS increased subsurface C storage compared to annual plants such as soybean or corn, and 4) N fertilization for the PCS hay crop (PC Sc) stimulated plant growth and water use, and soil organic carbon storage in the plant root zone. In effect, it appeared that decreasing soil water content over the growing season and increasing soil organic carbon due to the perennial grasses increased soil water infiltration.

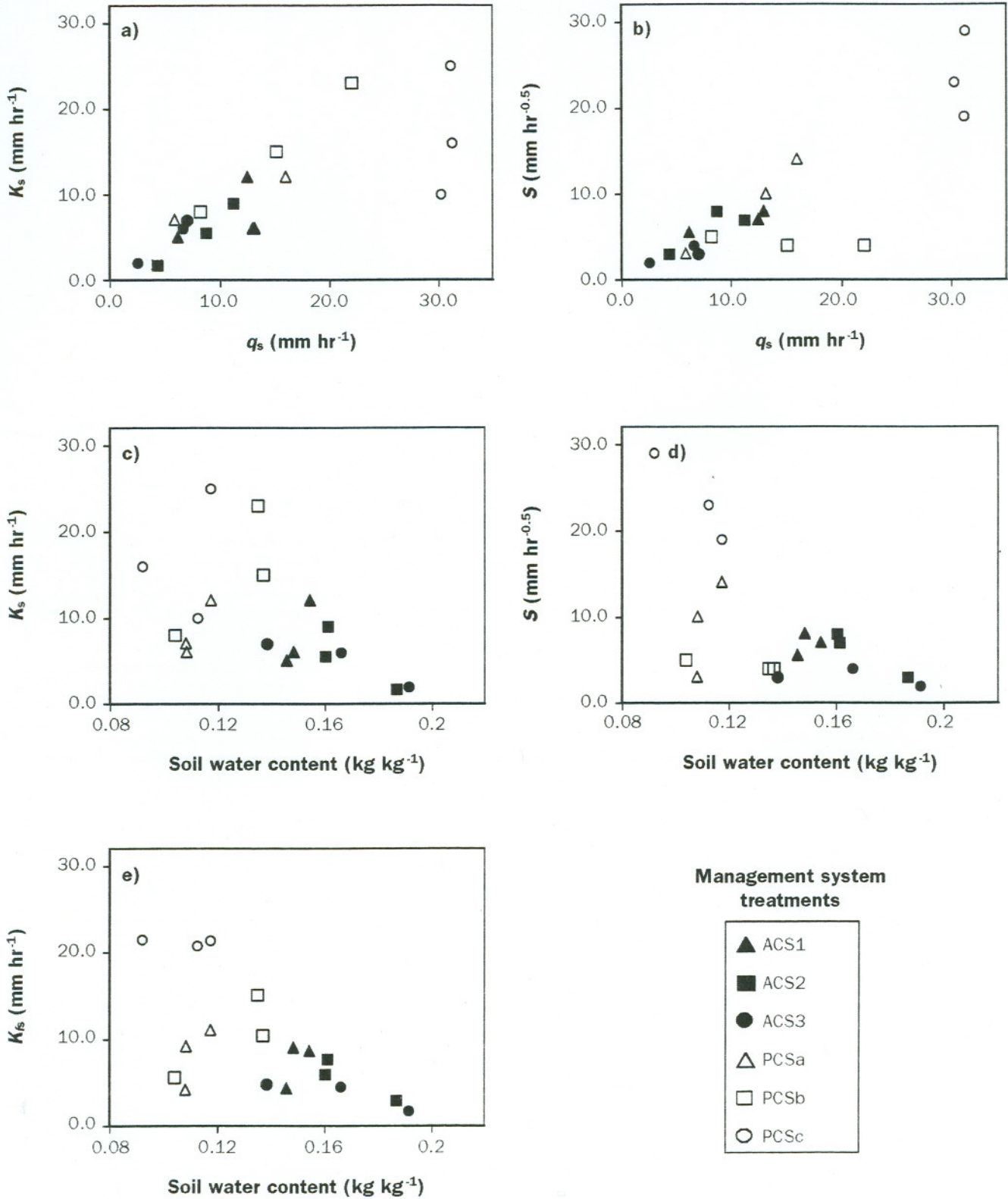
Water infiltration has been considered a very important factor for crop and water management. Accurate measurement of hydraulic properties in the field often requires intensive labor and time and therefore it is impractical for producers or researchers to conduct these tests over many fields. If these water infiltration characteristics could be estimated over variable landscapes by sensors, such as soil  $EC_e$ , analysis of hydrological response, management impact, and water quality over fields and watersheds could be greatly improved.

### Summary and Conclusion

Water infiltration measurements were taken to evaluate the effects of ACS and PCS management on a claypan soil. Soil properties and soil  $EC_e$  were also obtained to identify their relationship with infiltration parameters.

**Figure 2**

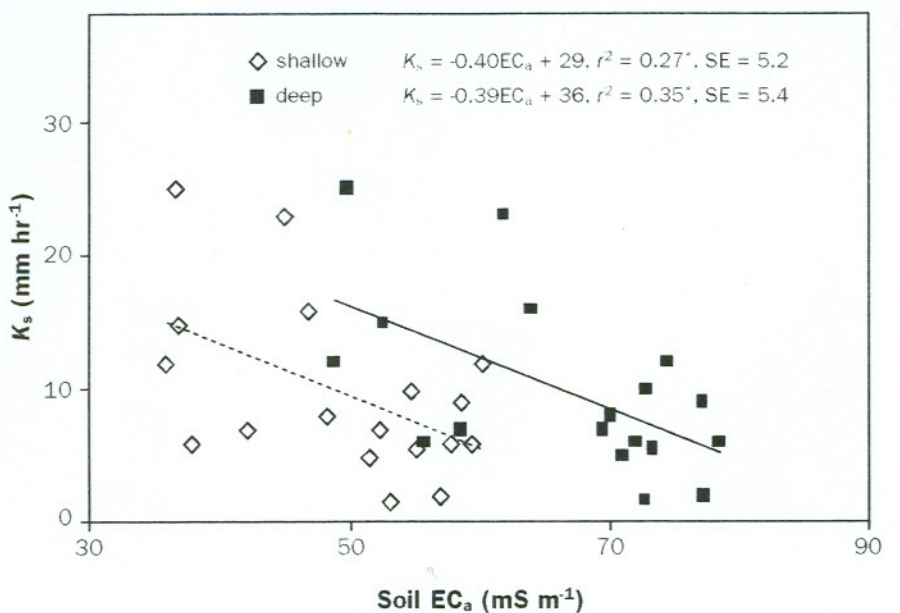
Relationships between calculated water infiltration properties ( $K_s$ ,  $S$ , and  $K_{fs}$ ) and measured properties ( $q_s$  and soil water content) for annual cropping system (ACS) and perennial cropping system (PCS) treatments. (See Table 1 for detailed description of specific ACS and PCS management treatments and Table 4 for description of  $K_s$ ,  $S$ , and  $K_{fs}$ ).





**Figure 3**

Relationships between soil  $EC_a$  and  $K_s$ . Both regression models are significant at the 0.05 probability level.



The Green and Ampt model was used to estimate water infiltration parameters from cumulative infiltration measurements.

We found water infiltration parameters ( $K_s$ ,  $S$ ,  $q_s$ , and  $K_f$ ) were greater with PCS than with ACS management. Concurrent, significant increases in soil organic carbon (36 percent) and aggregate stability (74 percent), and a decrease in antecedent soil water content was found after 12 yrs of PCS management compared to after 12 years of ACS management. These are considered critical properties when evaluating water infiltration as affected by management practices. With hay crop management (PCS), water infiltration was greatly increased over all other manage-

ment treatments. Water infiltration parameters were significantly correlated with soil water content and soil organic carbon. Estimated  $K_s$  was also correlated to shallow- ( $P = 0.05$ ) and deep- ( $P = 0.01$ ) sensed  $EC_a$ . Labor and time restrict characterization of water infiltration, but these findings suggest that  $EC_a$  sensors might be used for characterization of water infiltration parameters, particularly when antecedent soil water is judged to vary over the area of interest.

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**Table 4. Pearson correlation ( $r$ ) and probability of significance between water infiltration properties, sampled soil properties, and soil  $EC_a$  ( $n = 18$ ).**

property*	$K_{fs}$	S	$K_s$	SW	SOC	AS	$EC_{a-shallow}$	$EC_{a-deep}$
qs	1.00**	0.86**	0.79**	-0.61*	0.56*	0.24	-0.36	-0.41
$K_{fs}$		0.86**	0.79**	-0.63*	0.60**	0.28	-0.40	-0.44
S			0.45	-0.60**	0.51*	0.28	-0.23	-0.26
$K_s$				-0.48*	0.59**	0.25	-0.52*	-0.59**
SW					-0.68**	-0.63**	0.63**	0.60**
SOC						0.78**	-0.70**	-0.68**
AS							-0.55*	-0.55*
$EC_{a-shallow}$								0.97**

\*\* Significant at the 0.05 and 0.01 probability levels, respectively.

\*  $q_s$  = quasi-steady infiltration rate;  $K_{fs}$  = field hydraulic conductivity; S = sorptivity;  $K_s$  = saturated hydraulic conductivity; SW = soil water content; SOC = soil organic carbon; AS = aggregate stability;  $EC_{a-shallow}$  = shallow apparent soil electrical conductivity.



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