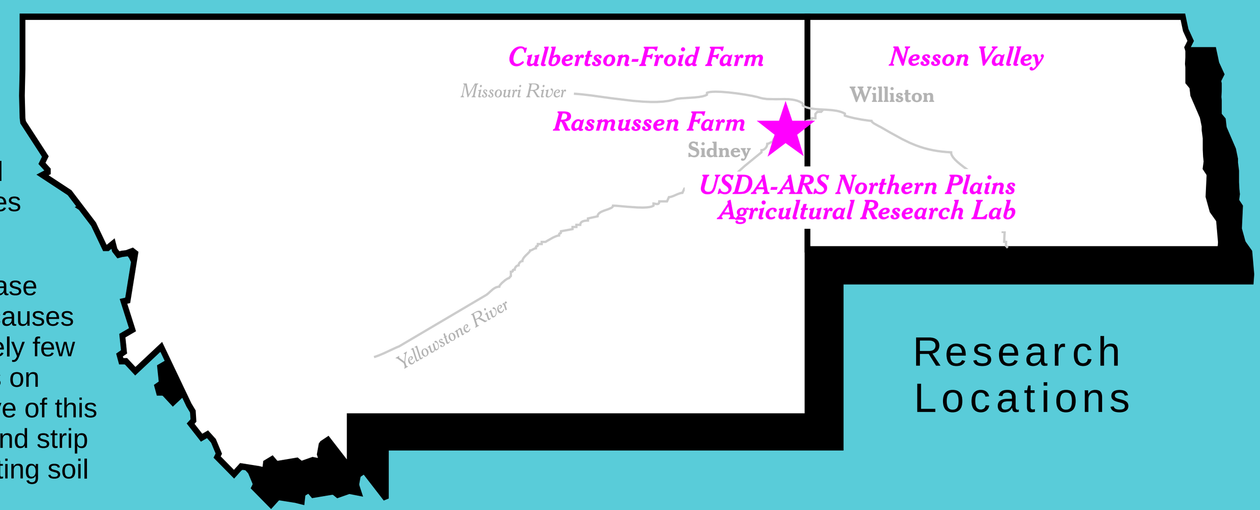
Tillage Effects on Field-Saturated Hydraulic Conductivity in Two Contrasting Soil Textures

Introduction

The rate at which water moves into soil (infiltration rate) and through soil (saturated hydraulic conductivity) depends on soil structure, pore size distribution and pore continuity (Bouma, 1991). These soil properties are all affected by tillage, which is one of the most influential management practices affecting soil physical and hydraulic characteristics.

Tillage can alter soil structure, creating macropores that considerably increase saturated hydraulic conductivity, the reverse being true when wheel traffic causes soil compaction and subsequent destruction of soil macropores. Yet relatively few studies have evaluated and compared the effects of various tillage systems on infiltration rate and saturated hydraulic conductivity of the soil. The objective of this study was to evaluate and compare the effect of conventional tillage (CT) and strip tillage (ST) systems on field-saturated hydraulic conductivity in two contrasting soil textures.



Research Locations

Materials and Methods

Study Sites and Soil Penetration Resistance Measurements

The study sites were situated on two common soil types in two sprinkler-irrigated fields within a semi-arid region of eastern Montana and western North Dakota. Field-saturated hydraulic conductivities were measured at two locations, one in North Dakota (Nesson) and the other in Montana (EARC). Soil penetration resistance was measured by inserting a hand-held digital penetrometer into the soil at the center of the crop rows within CT and ST plots at both locations (Table 1).

North Dakota (Nesson) Site

The North Dakota research site is located at the Nesson Valley Mon-Dak Irrigation Research and Development Project (approximately 37 km east of Williston, ND). The soil is mapped as Lihen sandy loam (sandy, mixed, frigid Entic Haplustoll).

The experimental design at the Nesson site was a strip block arrangement of a randomized complete block design with six replications. This study utilized data from the sugarbeet plots under both tillage systems. The measurements were made approximately 1 m apart in the crop row positions within CT and ST sugarbeet plots in June 2006.

Montana (EARC) Site

The Montana research site is located at the Montana State University Eastern Agricultural Research Center (EARC) (approximately 1 km north of Sidney, MT). The EARC soil is mapped as Savage clay loam (fine, smectitic, frigid Vertic Argiustolls).

The experimental design at the EARC was an unbalanced strip block arrangement with six or eight replications of each crop rotation, varying by year.

The field-saturated hydraulic conductivity measurements were made approximately 1 m apart in the crop row within CT and ST sugarbeet plots in June 2006.

Tillage Methods

Conventional Tillage (CT)

The CT plots at the Nesson Valley site were tilled just prior to planting in the spring of 2006. The plots were fertilized and disked 12 cm deep on 4/26/2006. The following day all plots were chisel plowed with straight shovels to a depth of 28 cm. One pass was made with a cultipacker (seedbed preparation implement) immediately following the chisel plowing.

Strip Tillage (ST)

The ST operation was completed at EARC on 9/13/2005 and at Nesson on 9/28/2005 using a strip tiller set to a depth of 20 cm with a straight coulter in front of a semi-parabolic shank followed by two wavy coulters and a crowsfoot packer wheel. A tube mounted on the rear of the shank placed dry fertilizer 10 cm deep in the tilled zone.

Conventional Tillage at Nesson Valley

Strip Tillage at Nesson Valley

J.D. Jabro, W.B. Stevens, R.G. Evans, W.M. Iversen

USDA-ARS Northern Plains Agricultural Research Laboratory, Sidney, Montana

Measurement of Field-Saturated Hydraulic Conductivity, K_{fs}

The K_{fs} for soil surface and subsurface layers was measured using a pressure infiltrometer (PI) and a Guelph Permeameter (GP), respectively.

Subsurface K_{fs} Measurements

In-situ subsurface K_{fs} ($L\,T^{-1}$) using a steady state flow rate of water from a cylindrical borehole augured to a given depth below the soil surface, was calculated using Richards' analysis (Reynolds et al., 1985):

$$K_{fs} = \frac{CQ}{\left[2\pi H^2 + C\pi r^2 + \left(\frac{2\pi H}{\alpha}\right)\right]} \quad [1]$$

where C is a dimensionless shape factor that depends primarily on the H/r ratio and soil texture/structure properties and is a function of both H and r (C = 0.803), Q is the steady-state flow rate out of the borehole ($L^3 T^{-1}$), H is the steady depth of water in the hole (L), r is the radius of the hole (L), and is a soil texture/structure parameter (L^{-1}), set to = 36 m^{-1} for sandy loam and = 12 m^{-1} for clay loam soil .

Soil Surface K_{fs} Measurements

One-dimensional water flow in the infiltration ring, followed by divergent three-dimensional flow below the ring, was calculated using

$$K_{fs} = \frac{GQ}{G\pi a^2 + a\left(H + \alpha^{-1}\right)} \quad [2]$$

where K_{fs} ($L\,T^{-1}$) is the field-saturated hydraulic conductivity at the soil surface, G is a dimensionless shape parameter determined by the numerical solution of Richard's equation, (Reynolds and Elrick, 2002) given as

$$G = 0.316\frac{d}{a} + 0.184 \quad [3]$$

Q is a steady-state flow rate out of the PI and into the soil ($L^3 T^{-1}$), is a soil texture/structure parameter (L^{-1}) identical to that in the Guelph Permeameter, d is the depth of ring insertion into the soil (L), and a is a radius of the stainless steel ring (L).

Results and Discussion

The ANOVA results of log-transformed K_{fs} at three soil depths under each tillage system at the Nesson and EARC sites are summarized in Table 2.

The values of K_{fs} as a function of soil depth under both CT and ST tillage systems at Nesson and EARC locations are presented in Figures 1 and 2, respectively. At both sites, K_{fs} measurements were higher in ST plots than in CT plots at the 9 - 15 cm depth. The differences in K_{fs} under CT may have been the result of variations in soil compaction within the 9 - 15 cm soil layer (Figs. 1 and 2).

Traditionally, the CT system consists of several more field passes of equipment in which the wheel traffic is not confined to the inter-row area. In the ST system, the heavy wheel traffic was confined to the inter-row area; thus K_{fs} measurements were never taken where the tractor tires had been driven and compacted the soil. Furthermore, the CT tillage consisted of vigorous tandem disking to the 10 - 12 cm depth, and chisel plowing to the 28 - 30 cm depth. Given that the GP wells were augered to the 9 - 14 cm depth and a 5 cm head was ponded, then the K_{fs} measurement zone ranged from the 4 - 9 cm depth to the 9 - 15 cm depth. Hence, some of the K_{fs} measurements were in the upper disked zone, while others were in the lower chisel plowed zone. The disked zone may have had a lower K_{fs} than the chisel plowed zone, due to the structure-destroying nature of the tandem disking process relative to the macropore-creating nature of the chisel plowing process.

Location	Depth (cm)	Soil penetration resistance (CI) (MPa) Conventional tillage	Strip tillage
Nesson	0 - 5	0.33	0.27
	5 - 10	0.71	0.53
	10 - 15	1.11	0.82
	15 - 20	1.42	1.07
	20 - 25	1.62	1.33
EARC			
	0 - 5	0.55	0.35
	5 - 10	0.61	0.45
	10 - 15	0.65	0.55
	15 - 20	0.73	0.70
	20 - 25	0.86	0.82

Table 1. Average penetration resistance (cone index, CI) across the row of two tillage systems at the Nesson (sandy loam) and EARC (clay loam) locations.

Location	Tillage	Field-saturated hydraulic conductivity, K_{fs} ($mm\ h^{-1}$) ††† ----------- Depth (cm) ----------- Surface	9 - 15	17 - 20
Nesson		1.814 a† A††	1.398 aB	1.506 aB
EARC		1.668 bA	0.688 bB	0.602 bB
	CT	1.728 aA	0.868 bB	1.027 aB
	ST	1.754 aA	1.218 aB	1.082 aB

Table 2. Effect of soil depth on field-saturated hydraulic conductivity as averaged across two locations and two tillage systems. Soil texture was sandy loam and clay loam at the Nesson and EARC locations, respectively.

† Different lower case letters indicate significantly different within a column at P < 0.05 using the least square means test.

†† Different upper case letters indicate significantly different within a row at P < 0.05 using the least square means test.

††† The analysis in based on log-transformed data.

Figure 1. Field-saturated hydraulic conductivity (K_{fs}) as affected by depth and tillage (conventional and strip) at the Nesson location. Error bars are two standard errors of the mean.

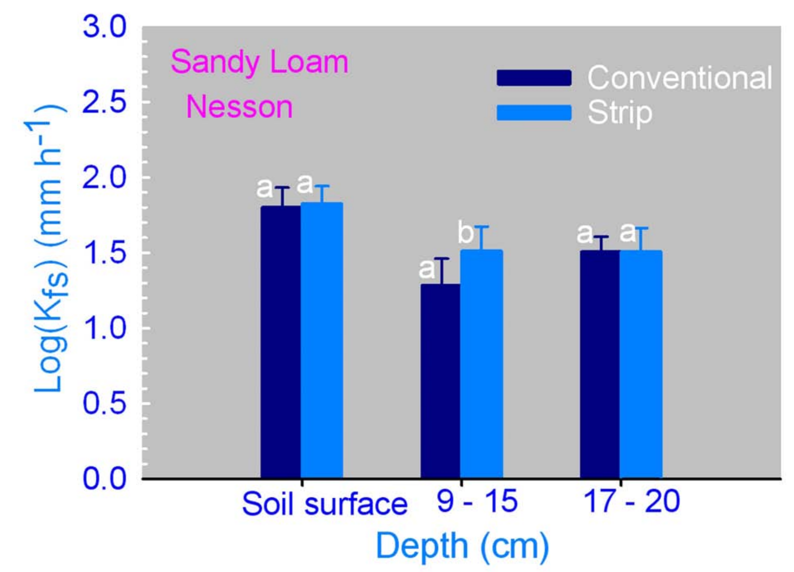
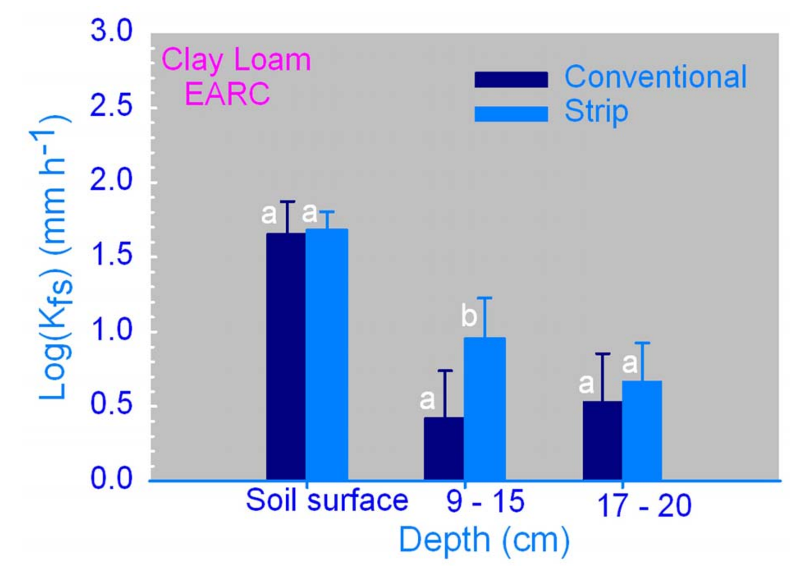


Figure 2. Field-saturated hydraulic conductivity (Kfs) as affected by depth and tillage (conventional and strip) at the EARC location. Error bars are two standard errors of the mean.



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Conclusions

- Soil surface K_{fs} values were significantly higher than those at depths of 9 - 15 and 17 - 20 cm regardless of location or tillage system.
- K_{fs} decreased with depth regardless of soil type or tillage system. The variation in K_{fs} values in soil at a depth of 9 - 15 cm were a likely a function of the differences in soil compaction peculiar to the CT and ST systems.
- The differences can be attributed to the fact that the GP measurements at a depth of 9 - 15 cm tended to straddle the two CT tillage zones.
- Soil tillage system had more effect on K_{fs} values at the 9 - 15 cm depth compared to values at the soil surface and the 17- 20 cm depth regardless of soil type or tillage system.
- Strip tillage plots likely had better volume of macropores than CT plots, producing higher water flow through the ST soil profile and consequently enhanced water storage capability.
- Whether CT or ST, the tillage system chosen significantly impacts soil hydraulic properties and may affect both crop growth and yield.