WATER INFILTRATION INTO A GLACIAL TILL SOIL FOLLOWING SUBSOILING AND SECONDARY TILLAGE

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Introduction

Water limits crop production in the semiarid northern Great Plains of the United States. Summer fallow is commonly practiced to store water in the soil for use by a later crop (Haas, *et al.*, 1974). However, high evaporation rates makes summer fallowing inefficient in storing water (Tanka, 1985; Tanka and Aase, 1987). Additionally, the fallow-wheat (*Triticum aestivum* L.) crop sequence has been implicated as the cause of serious declines in soil organic carbon (Rasmussen and Parton, 1994). A recent report by Aase and Pikul (1995) showed that annually grown spring wheat was an acceptable alternative to the traditional fallow-wheat crop sequence in eastern Montana, USA. To successfully grow a crop every year, however, it is essential to conserve as much precipitation as possible between harvest and seeding.

Specialized tillage is thought to improve water infiltration and soil water storage. Pikul *et al.* (1996) have shown that soil ripping on the contour may improve water infiltration into frozen soil and possibly increase soil water storage. Objectives were to 1) determine the effect of soil ripping on water infiltration and 2) evaluate the durability of tillage induced soil structure following repeated wetting and drying cycles.

Methods

The experimental area has been farmed in a fallow-wheat cropping sequence since 1975. Primary tillage was done in the spring with a tandem disk at about 0.1 m deep. Tillage for summer fallow was with sweeps at about 0.1 m deep and rod weeder.

Tillage plots were established in June 1994. Customary fallow tillage was deferred to avoid disturbance of standing wheat residue from the 1993 crop. The last soil disturbance was at wheat planting in 1993, since herbicides were used to kill plants on the infiltration plots. Experimental design was randomized with 4 replications. Soil was a Dooley sandy loam (fine-loamy, mixed typic Argiborolls). Tillage treatments were: 1) no tillage (NT), 2) soil ripped to a depth of 0.3 m (R), and 3) soil ripped to a depth of 0.3 m and followed by medium crown sweeps at about 0.1 m deep (RS). Ripping was with a single parabolic subsoiling tool.

A Palouse rainfall simulator (Bubenzer *et al.*,1985) was used to apply water at a rate of about 40 mm h^{-1} to 1.16 by 1.16-m infiltration frames. Electrical conductivity of Missouri River water (Culbertson, MT municipal water supply) used for the infiltration tests was 0.7 dS m^{-1}, concentration of cations was 0.157 g l^{-1}, and SAR was 13.6. Simulated rainfall mimics low intensity storms of the inland Pacific Northwest. Typical summer rainstorms in the northern Great Plains are high intensity and short duration. The Palouse simulator produces drop sizes that are about 1.3 to 1.8 mm diameter. By comparison, natural rainfall with intensities of about 50 mm h^{-1} have drop sizes that are about 1 to 5 mm diameter (Wischmeier and Smith, 1958). Therefore, the test soil was not exposed to rainfall energy that exceeded that of naturally occurring storms.

Infiltration frames were constructed of heavy gauge steel. To install the frame to a depth of 0.25 m, we carefully dug a shallow and narrow trench around the outside of the frame. As layers of soil were removed, the infiltration frame was forced downward to enclose an undisturbed soil monolith. Soil was then back filled and compacted around the outside of the frame. Inside edges of the infiltration frames were sealed with bentonite clay to prevent any water leakage along the metal-soil interface. Four frames were installed on each treatment.

Water application rate from the rainfall simulator was determined at the start and finish of each infiltration test by collecting the water from a 1.35-m^2 calibration pan placed over the infiltration frame. Infiltration was calculated as the difference between application rate and runoff rate. Runoff water was removed from within the infiltration frame by vacuum. Water was applied for 3 hours on Day 1, 2, and 3. The soil drained for about 20 hours following each water application.

Soil bulk density (BD) and penetration resistance (PR) were measured after the infiltration tests. Within each frame, 4 intact 0.3 m cores were cut into 0.03 m increments, resulting in 16 measurements of soil BD for each 0.03 m depth increment. Pikul and Aase (1995) describe procedures to measure BD. Gravimetric water content, determined on these cores, was converted to a volumetric basis using measured BD. Penetration resistance was measured with a 30° cone penetrometer that had a base area of 645 mm^2. Measurements were taken within each frame at 9 positions along 2 transects oriented perpendicular to the direction of tillage. At each transect position, PR was measured in 0.075 m depth increments to a depth of 0.38 m. A surface map using depth (x), transect position (y), and PR (z) was prepared for each transect. Surface area was calculated for each map and used as an index of soil subsidence.

Values of bulk density, final infiltration, and subsidence index were tested for significance using analysis of variance and least significant differences (LSD) at $P=0.05$.

Results

The test soil is a glacial till and there is large spatial variability in soil texture at depths greater than 0.3 m. In the upper 0.3 m, sand content decreased linearly from 67% in the top 0.03 m to 62% at 0.30 m. Clay content increased from 16% to 21% at these respective depths. Soil organic carbon in the top 0.03 m was 10 g kg^{-1}.

Measured water infiltration rates support local observations. Early in the growing season

Table 1. Final water infiltration rates measured during the last 0.75 hr of three-hour infiltration tests. Tests were made on consecutive days.

Treatment	Day 1	Day 2	Day 3
	------- mm hr^{-1} -------		
No till	28.2	8.5	5.6
Rip	41.0	17.1	11.4
Rip and sweep	38.6	8.1	4.2
LSD (0.05)	6.2	2.3	2.9

runoff is rarely seen; by midsummer, however, runoff can be severe on smooth tilled fields after high-intensity thunderstorms. Infiltration measurements (Table 1) show that final infiltration on all treatments decreased with each subsequent artificial rain. On the RS treatment, final infiltration rate decreased from 38.6 mm hr^{-1} on day 1 to 4.2 mm hr^{-1} on day 3. Final infiltration on the R treatment on day 3 was 11.4 mm hr^{-1} and at least twice that of NT and RS treatments. Tillage induced preferential flow paths that were continuous with the soil surface likely contributed to the greater water infiltration on the R treatment.

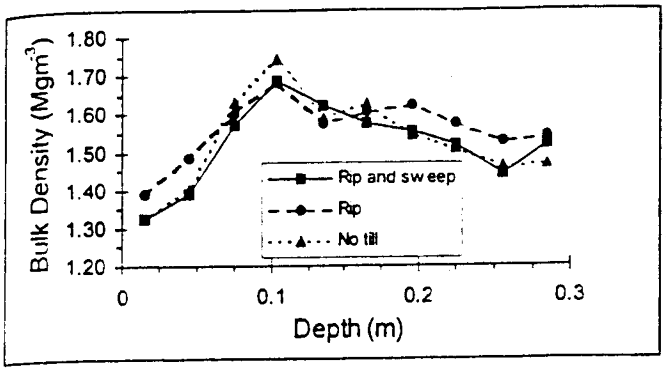

Figure 1. Soil bulk density after three artificial rainstorms.

Soil bulk density profiles show features common to all infiltration test plots (Fig. 1). We think that the zone of maximum bulk density at about 0.1 m depth is a consequence of repeated use of shallow sweep tillage. There were no significant differences in bulk density among treatments. Bulk density profiles on the R and RS treatments were taken about 0.25 m away from the path of the subsoiling tool in an area not disturbed by subsoiling.

Soil PR measurements were used as an index of soil subsidence following three consecutive artificial rainstorms. Measurements were mapped as a 3-dimensional surface plot (Fig. 2). Surface plots provide a way to visualize tillage induced soil structure and a means to quantify changes in structure as a consequence of repeated wetting and drying. An example of one of these maps is shown in Figure 2 for one replication of the rip treatment. In this figure, the path of the subsoil tool is at transect position 50. The low penetration values, that are roughly in the shape of a "V", outline a zone of soil that was fractured by the parabolic subsoil tool. Tillage induced structure provides preferential water flow paths which are important to maintain rapid water infiltration.

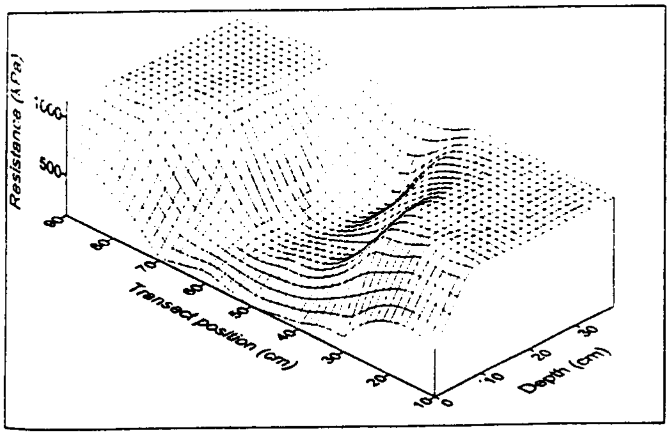

Figure 2. Penetration resistance on the rip treatment after three artificial rainstorms.

Subsidence index, which is the ratio of surface area to basal area, was not significantly different between R and RS treatments following three consecutive artificial rains. These results indirectly suggest that there were also no differences in tillage induced soil structure between the two tillage treatments. Recall that on the RS treatment secondary tillage was about 0.1 m deep with 0.45 m wide sweeps. Surface tillage on the RS treatment produced a relatively smooth surface that slaked quickly, as evidenced by reduced infiltration.

Soil penetration resistance depends on depth distribution of soil water. Volumetric water content (not shown) was not different among treatments. Average volumetric water content of the top 0.1 m of soil was 0.15 m^3m^{-3} and 0.17 m^3m^{-3} for the 0.1 to 0.3 m depth.

Conclusions

Objectives of tillage are to incorporate residues or amendments, control weeds, loosen tillage or compaction pans and prepare seed beds. Tillage to specifically prepare fields for improved water infiltration is generally not a consideration. Our results show the difficulty of preparing a sandy loam soil for both improved water infiltration and desirable seed bed. Smooth surface conditions following sweep tillage were a detriment to water infiltration because of the rapid slaking of the surface during the first of three artificial rain storms. Penetration resistance measurements suggested that there was similar internal soil structure on both the rip treatment and the rip-sweep treatment. In the case of the rip treatment, infiltration rates were maintained because internal macropores were surface connected as opposed to the rip-sweep treatment where water infiltration was limited by the hydraulic conductivity of the crusted surface. Water infiltration was improved by ripping but beneficial effects of ripping on water infiltration were short lived when ripping was immediately followed by secondary tillage.

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