Reprinted from the *Soil Science Society of America Journal*
Volume 53, no. 1, January-February 1989
677 South Segoe Rd., Madison, WI 53711 USA

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Changes in Infiltration Under Alfalfa as Influenced by Time and Wheel Traffic

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ABSTRACT

Infiltration rates were measured for alfalfa, (*Medicago sativa* L., cv. WL514) subjected to treatments where wheel traffic was varied in terms of area covered and time of application on a Wasco sandy loam (coarse-loamy, mixed, nonacid thermic Xeric Torriorthent). Traffic treatments were (i) No-traffic, (ii) Preplant, (iii) Repeated, and (iv) traffic similar to what a grower would apply. Infiltration rates increased for all treatments, with increases being 240% for treatments without harvest traffic and 140% for treatments with harvest traffic. Increases in infiltration were related to decreases in stand density. Slight packing (traffic) applied before the soil was flood-irrigated in 1983 increased infiltration rates 20% compared to flooding loosened soil (no traffic). Harvest traffic resulted in slower water movement in the soil.

IN THE IRRIGATED southwestern USA, a major effect of soil compaction is reduction in the infiltration rate, resulting in insufficient water being available for optimum crop growth (Goldhammer and Peterson, 1984). Entry of water into soil occurs by two processes: (i) piston-like flow through the soil matrix, and (ii) flow through macropores without displacement of matrix water (Thomas and Phillips, 1979).

Bulk density and soil texture greatly affect piston-like flow of water through soil. Patel and Singh (1981) reported that if the bulk density in a coarse-textured soil was increased from 1.7 to 1.9 Mg m^{-3}, hydraulic conductivity decreased from 1.4×10^{-3} to 5.5×10^{-6} mm s^{-1}. Soil bulk density has little or no relationship to water flow through macropores.

Macropores are formed in cropped soils as a result of decomposition of roots (Barley, 1954), wetting and drying cycles, freezing and thawing, and earthworms. Root growth initially may decrease infiltration rates, but decomposition of roots leave channels or macropores which result in increased infiltration rates (Barley, 1954). Water flow through macropores may be greater in soils that are not tilled frequently, such as alfalfa because the macropores are not disrupted. Disparte (1987) measured higher infiltration rates in plots planted to alfalfa compared to unplanted control plots. White (1985) presented data giving a potential infiltration rate of 4.4×10^{-4} mm ha^{-1} when a soil had a fractional macropore area of 0.01 (2-mm diam. pores). Edwards et al. (1979) developed a model which shows that the number of holes per unit soil area, diameter, and depth of the holes influence infiltration rates.

Taylor (1983) defined zone production systems as crop production systems in which the uncompacted crop zone and traffic lanes are separated distinctly and permanently. This study is part of a series of experiments being conducted at the U.S. Cotton Research Station on zone production systems using alfalfa (Rechel et al., 1987; Meek et al., 1988). Other experiments with zone production systems are being conducted in England (Soane, 1975), Netherlands (Lamers et al., 1986), and Israel (Hadas, 1987).

The objective of this study was to define and characterize water flow into and through the soil in an alfalfa field subject to preplant and harvest traffic.

MATERIALS AND METHODS

The research was conducted at the U.S. Cotton Research Station, Shafter, CA, 111 m above sea level and receiving an average of 159 mm of rainfall per year with little rainfall from May to September. The soil was a Wasco sandy loam.

Alfalfa, nonwinter-dormant cultivar WL514, was sown in October 1982. Each plot was 8 m wide by 30 m long. All

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Published in Soil Sci. Soc. Am. J. 53:238–241 (1989).

plots were rotary tilled to 0.15 m and chiseled with 0.33-m spaced shanks to a depth of 0.54 m in 0.18-m increments in August 1982. This tillage operation established a uniform soil condition for planting by reducing variation due to previous soil management. In February 1983, triple superphosphate (20% available P) was broadcast at 160 kg P/ha. Phosphorus levels in the tissue were adequate. The alfalfa was sprinkler-irrigated in October 1982 (to enhance germination), November 1982, and early April 1983. Plots were flood-irrigated for the first time on 25 April 1983, and all subsequent irrigations to each plot were by flooding. The alfalfa was irrigated when 50% of the available water was depleted in at least 25% of the plots at the 0.3- to 0.6-m index depth.

Treatments were:

1. *No Traffic.* Alfalfa was seeded into the loosened soil, and all traffic was excluded.
2. *Preplant.* The loosened soil surface was allowed to dry then compacted with a crawler tractor (International TD9,[1] 2640 kg applied to each track) followed by a rubber-tired tractor (John Deere 4020) with 18.4–34, 6-ply rear tires with a 2020-kg load applied to each tire inflated to 150 kPa and 10.0–16, 6-ply front tires with a 823-kg load applied to each tire inflated to 138 kPa. Both tractors covered 100% of the soil surface with tracks or tires. There was no harvest traffic applied after alfalfa was planted.
3. *Repeated.* The plots were treated as the preplant treatment before planting with harvest traffic being applied after planting. Each plot was trafficked (100% of the soil surface) 3 to 5 d after each harvest by single passes of a rubber-tired tractor (same as one used to compact preplant treatment).
4. *Grower.* Traffic patterns were based on a local survey of farmer practices. The initial preplant condition consisted of two tracks in the loosened soil to represent the alfalfa planter. Subsequent traffic during each harvest was aligned in a pattern to represent a swather, rake, baler, and bale wagon. This wheel pattern created many distinct traffic zones (ranging from none to heavy traffic) over the length of the plot and resulted in 48% of the soil surface receiving wheel traffic.

All plots were cut at the same time, when 50 to 70% of the regrowth buds were 10 to 20 mm in length. Traffic patterns were applied 3 to 5 d after cutting, representing passes of the baler and bale wagon which cause more damage than the passes of the rake and swather (Sheesley et al., 1974). Traffic damage from the swather and rake are minimal because of short time period after cutting; for convenience this pattern was applied at the same time as the baler operations. The first harvest was on 1 April 1983; but because the soil was wet from a rain, the first traffic was not applied until 17 May, after the second harvest.

All cultural operations and measurements were made with a wide tractive research vehicle (WTRV) spanning each plot. The WTRV travels on permanent wheel paths, and all operations were conducted without applying traffic to the area planted to alfalfa. A description of the vehicle is given by Carter et al. (1987). Some measurements were taken from small portable catwalks which spanned each plot. No foot traffic was allowed in any plot.

Infiltration rates were measured by adding approximately 0.12 m of water to each plot and measuring the decrease in water level after 16, 25, 36, 49, 64, 81, 100, 121, 144, 169, 196, 225, and 256 min. Measurement time was started when half of the plot was covered with water. Plots were flooded completely in about 15 min. Infiltration rates as a function of time were graphed and the rate at 2 h after initial infiltration was selected as the reference infiltration rate. Two hours allowed sufficient time for the rate to stabilize. Water intake rates were measured in 1983 (25 April, 19 May, 1 June, 15 July, and 8 Sept.), 1984 (26 March, 24 July, and 11 Sept.), 1985 (1 April, 12 Aug., 27 Aug, and 16 Sept.), and 10 June 1986.

[1] Trade and company names are used for the benefit of readers and do not imply endorsement by the USDA.

Table 1. Hydraulic conductivity and bulk density of soil cores sampled from four depths in March–May 1985.†

Treatment	Soil depth, m 0.02–0.11	0.20–0.29	0.49–0.58	0.62–0.71
	mm/h			
No traffic	72	61	47	29
Preplant	72	43	47	90
Repeated	36	61	36	47
Grower	25	25	54	36
LSD 0.05 = 41				
Means				
Without traffic	72	52	47	60
With traffic	30	43	45	42
LSD 0.05 = 29				
	Bulk density, Mg/m^3			
No traffic	1.62	1.71	1.70	1.74
Preplant	1.70	1.73	1.67	1.71
Repeated	1.83	1.75	1.70	1.71
Grwoer	1.82	1.81	1.73	1.75
LSD 0.05 = 0.05				
Means				
Without traffic	1.66	1.72	1.68	1.72
With traffic	1.82	1.78	1.72	1.74
LSD 0.05 = 0.03				

† Harvest traffic: without = no traffic and preplant traffic treatments together; with = repeated and grower together.

In the spring 1985, (Table 1) soil cores were removed from the 0.02- to 0.11-, 0.20- to 0.29-, 0.49- to 0.58- and 0.62- to 0.71-m depths for measurement of hydraulic conductivity. Cores were obtained with a soil core sampler (Soilmoisture Model 212, P.O. Box 30025, Santa Barbara, CA 93105) which removed a 0.09-m long by 0.077-m diameter core. Samples were taken 3 to 5 d after the field was irrigated. In the grower treatment, samples were taken only from the zone receiving heavy traffic. In the laboratory, the soil samples were flushed with CO_2 (Jarrett and Hoover, 1984) and then hydraulic conductivity was measured using air free, boiled water. Cores were placed in a rack, a constant head of 5 cm maintained by a mariotte bottle and the flow rate through the cores measured after equilibrium. Soil cores were taken March through May 1985. One core was taken per plot from each depth. The tillage interface in 1985 was measured at the 0.50- to 0.55-m depth for the repeated treatment and 0.55- to 0.60-m for the none traffic and preplant treatments.

Pore size and continuity were measured in October 1986 (in all treatments except the grower treatment) at four locations in each plot in the field. Measurements were not made in the grower treatment because it would have required an excessive amount of time to characterize each of the traffic lanes. The locations were in a row with about 0.30 m between each cylinder. One thousand milliliters of a 0.5% (weight: weight) aqueous solution of methylene blue was added to each 0.20-m diam. cylinder (driven into the soil 75 mm). The solution infiltrated in about 20 min. The next day, a trench was dug about 0.3 m in front of the row of cylinders, leaving a vertical face (0.6 m in depth and 3 m wide). The vertical face was sliced horizontally across at the 0.20, 0.30, 0.40, and 0.50-m depths. When spots of blue were found, soil samples were taken. Samples were examined microscopically to determine number and diameter of stained pores. Pores of diameter <0.5 mm were too numerous to be counted.

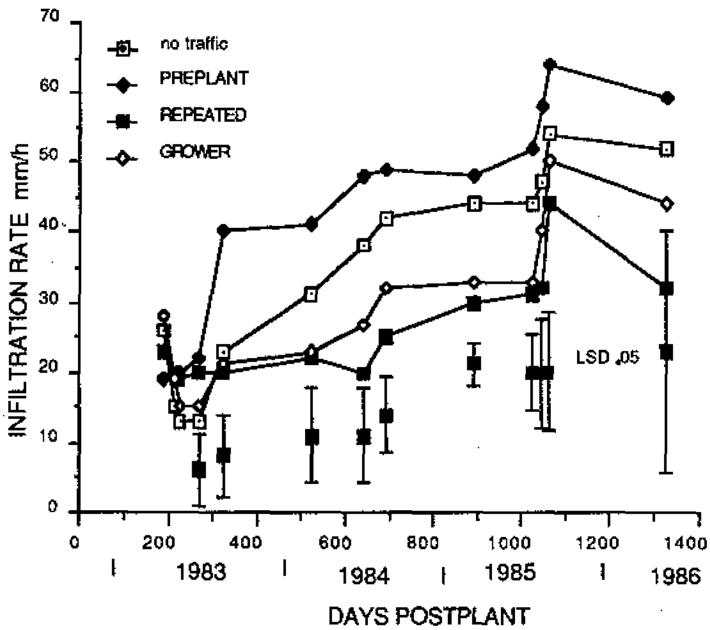

Fig. 1. Infiltration rates in plots under alfalfa culture (1983–1986) as influenced by time and wheel traffic. Rates are for 2 h after plots were flooded.

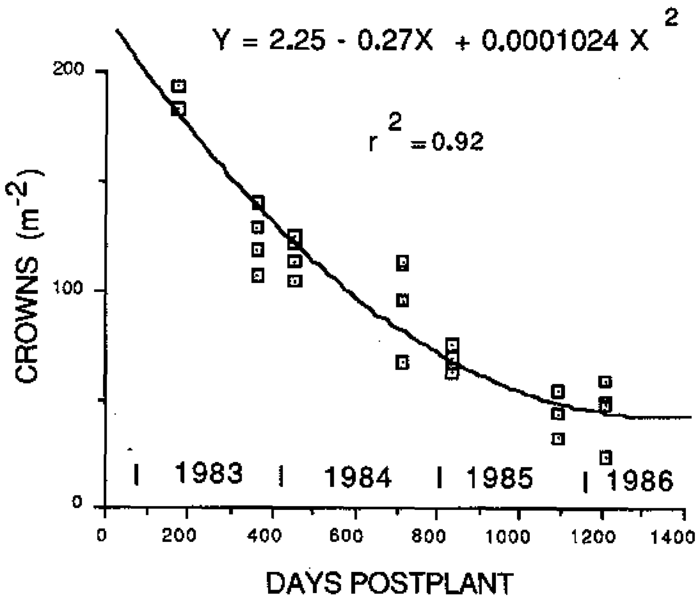

Fig. 2. Live crown density as a function of days after planting. Points are for an average of a treatment for one sampling date.

Crown density was measured by counting live crowns in a square area 300 by 300 mm. Four squares were counted in each plot. Counts were made in 1983 (April and October), 1984 (January and September), 1985 (January and October), and February 1986.

Statistical Analysis

The experimental design used for all comparisons was a randomized complete block with six replications for the main plots, repeated over depth for bulk density and hydraulic conductivity data and repeated over time for infiltration data.

RESULTS

From May 1983 to September 1985 water infiltration rates increased (Fig. 1). The percent increase (May 1983 to September 1985) was 260, 220, 120, and 160 for the treatments no traffic, preplant, repeated, and grower, respectively. There were no significant differences in water infiltration rates during the two flood irrigations in April and May 1983. Initially the water intake rate of the preplant treatment increased rapidly, and the rate was almost double that of the other treatments by September 1983. Water intake rates for the treatments with harvest traffic (repeated and grower) were 67% of the treatments without harvest traffic (no traffic and preplant) if data were pooled for 1984, 1985, and 1986.

Most of these increases in infiltration occurred in late summer (Fig. 1). In 1985 water infiltration rates increased only slightly (4%) from 1 May to 12 Aug., but the increases were large (33%) from 12 Aug. to 16 Sept. (values for all four treatments averaged).

Density of live crowns decreased from 1983 to 1986 (Fig. 2). Density was 190 crowns/m^2 in April 1983 but decreased to 44 crowns/m^2 by February 1986. Crown density varied slightly among treatments with competition and disease probably being the main two factors causing stand decline.

Hydraulic Conductivity

There was no significant differences in hydraulic conductivity with respect to depth averaging (for all treatments) between 46 and 51 mm h^{-1}.

Treatments resulted in significant differences in hydraulic conductivity at the 0.02- to 0.11-m and 0.62- to 0.71-m depths. The grower treatment had a significantly lower hydraulic conductivity than the no traffic or preplant treatments at the 0.02- to 0.11-m depths. Hydraulic conductivity was significantly higher in the preplant treatment at the 0.62-to 0.71-m depth compared to all other treatments.

If treatments with harvest traffic were pooled and compared to combined values from those with no harvest traffic, there was a significant difference at the 0.02- to 0.11-m depth. Hydraulic conductivity was 2.5 times higher at the 0.02- to 0.11-m depth for treatments without harvest traffic than for treatments with harvest traffic. This difference corresponded to an increase in bulk density from 1.66 to 1.82 Mg m^{-3}. Hydraulic conductivity (K) was related to bulk density (ρ_b) at the 0- to 0.3-m depth by the formula $K = 466-239\ \rho_b$ ($r^2 = 0.76$). No significant relationships existed at the 0.49- to 0.71-m depths between hydraulic conductivity and bulk density. Harvest traffic resulted in a small increase in bulk density at the 0.20- to 0.29-m and 0.49- to 0.58-m depths without a significant increase in hydraulic conductivity.

Root Channels

A large number of channels in the soil profile were open to the surface (Fig. 3). The decrease in number of channels with depth was similar for all treatments, but the numbers were always less for treatments with harvest traffic than with no harvest traffic. Twenty-seven percent of the pores at the 0.20-m depth extended to the 0.50-m depth (average of all treatments). The number of pores for various size ranges was similar for all four depths (0.2, 0.3, 0.4, and 0.5 m) with 68, 24, and 8% of the pores in the 0.5- to 2.5-, 2.5- to

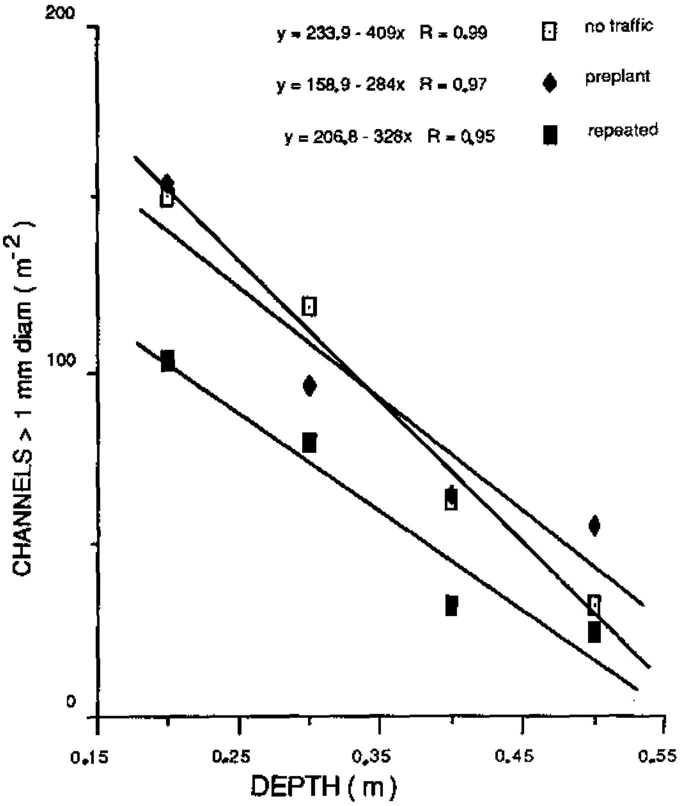

Fig. 3. Number of channels > 1 mm in diam. per m^2 as a function of depth in the soil profile.

4.5-, and 4.5- to 10.5-mm diam. sizes, respectively. Essentially all of the channels were round and often times parts of roots such as the periderm would be visible.

DISCUSSION

Infiltration rates in a sandy loam under alfalfa culture doubled or tripled during a 3-yr period. Increases in bulk density near the soil surface (Meek et al., 1988) did not result in the large decreases in infiltration rate measured by Patel and Singh (1981), but infiltration rates actually increased. Water flow through root channels allowed water to bypass compacted surface layers. Proebsting (1952) also found that alfalfa increased infiltration in a long-term rotation, compared to a clean-cultivated control.

Harvest traffic had an effect on water movement in the soil mainly because of the increase in bulk density near the soil surface. Harvest traffic reduced hydraulic conductivity at the 0.02- to 0.11-m depth by 60% compared to that of no-harvest traffic treatments. A large number of channels were open to the surface even if harvest traffic was applied to 100% of the soil surface. Alfalfa crowns and litter from previous harvests may have protected the top of channels and prevented closure from harvest traffic.

Infiltration (data averaged for 1984, 1985, and 1986) of loosened soil flood irrigated without prior packing (no traffic treatment) was 17% lower compared to a soil (preplant) that was packed lightly before the first flood irrigation. Factors causing this decrease were not defined adequately by this experiment. Loosened soil had very high infiltration rates during the first flood irrigation which may have caused soil particles to move downward until filtered out below the tillage layer. With packing before flooding, soil particles were held in place in the top 0.3 m and would be less likely to reorient or move downward. There is some evidence of soil movement since hydraulic conductivity below the tillage layer was much higher for the preplant compared to the no traffic treatment. Infiltration rate increased in late summer relative to the earlier part of the year. This increased rate may have resulted from the higher summer temperature which would increase decomposition of dead roots, leaving more channels for water flow.

CONCLUSIONS

Infiltration in an alfalfa field was dominated by flow through macropores (old root channels). Macropores allowed water flow to bypass soil which had been compacted by harvest traffic. Decrease in alfalfa stand density from 190 crowns/m^2 (April 1983) to 44 crowns/m^2 (February 1986) and subsequent decay of tap roots provided many channels for water flow. Flood irrigation of loose soil resulted in much lower infiltration rates the next year compared to soil that had been lightly compacted before the first flood irrigation.

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