Reprinted from the *Soil Science Society of America Journal*
Volume 54, no. 2, March-April 1990
677 South Segoe Rd., Madison, WI 53711 USA

Infiltration Rate as Affected by an Alfalfa and No-till Cotton Cropping System

B. D. Meek,* W. R. DeTar, D. Rolph, E. R. Rechel, and L. M. Carter

ABSTRACT

Previous studies measured a long-term increase in infiltration rate in a sandy loam soil with time when alfalfa (*Medicago sativa* L., cv. WL514) was grown. Cotton (*Gossypium hirsutum* L.) was direct-planted into alfalfa to determine if the high infiltration rates measured under alfalfa culture could be maintained in cotton under either a till or no-till system. Treatments were no-till or tillage to the 0.15-m depth just before the cotton was planted. Prior compaction levels created by harvest traffic applied to the alfalfa made the soil loose or compacted. Cotton was planted flat and irrigated as a basin. Infiltration rates measured 2 h after water was applied and averaged for the season were 101 (no-till, loose), 56 (till, loose), 82 (no-till, compacted), and 42 mm/h (till, compacted). All the infiltration rates were much higher than normally measured for cotton in these soils. Water flow in the 5-yr-old alfalfa was determined to be mainly through the soil macropore system. High infiltration rates measured in the no-till cotton were also probably the result of flow through the macropores.

INFILTRATION RATE in a sandy loam soil in the field is affected by five major factors: (i) aggregation (Tisdall and Adem, 1986), (ii) surface seal (Moore, 1981), (iii) bulk density (Patel and Singh, 1981), (iv) natural channels or macropores (Thomas and Phillips, 1979), and (v) restrictive layers below the surface (Schuh et al., 1984). Flow of soil water occurs by displacement (piston-like flow) and by nondisplacement of matrix water (flow down channels or macropores). Partial displacement is a combination of the two and is what usually occurs in a structured soil and cropped soils under minimum tillage. The macropore system is especially important in cropping systems using perennial crops. For example, Disparte (1987) measured increased infiltration rates when alfalfa was grown compared with a nonplanted control. Proebsting (1952) measured an increase in infiltration rate when alfalfa was grown in a long-term rotation compared with fallow or annual crops.

Alfalfa is used by growers to improve soil, but the exact nature of the improvement has not been well documented (Gardner and Robertson, 1954). Meek et al. (1989) measured large increases in infiltration rate with time when alfalfa was grown for 4 yr. Growing alfalfa reduces the infiltration rate at first, but later, when roots start to decompose, the rate increases (Barley, 1954). Disparte (1987) found a positive correlation between increases in infiltration caused by a crop and the size of the tap root. The effect of these root channels on infiltration rate during the succeeding crop needs to be defined.

No-till cropping systems will preserve the macropore flow system from one crop to the next (Edwards et al., 1988). It may not be possible to preserve the macropore system developed under a perennial crop such as alfalfa when it is succeeded by thorough tillage. Cotton production with conventional tillage may include up to eight tillage operations before planting (Carter and Colwick, 1971). These tillage operations compact the soil, increase breakdown of crop residues, and destroy natural channels that convey water to the root zone.

B.D. Meek, USDA-ARS, Soil and Water Management Research Unit, 3793 N 3600 East, Kimberly, ID 83341; W.R. DeTar, E.R. Rechel, and L.M. Carter, USDA-ARS, U.S. Cotton Res. Stn., 17053 Shafter Ave., Shafter, CA 93263; D. Rolph, 245 W. Broadway, Suite 350, Long Beach, CA 90802. *Corresponding author.

Published in Soil Sci. Soc. Am. J. 54:505–508 (1990).

Infiltration rate of soil can be increased by reducing surface sealing or preventing soil compaction. Bulk density can be maintained at low levels by eliminating or reducing wheel traffic (Meek et al., 1988). No-till systems drastically reduce surface sealing because of the residue left on the surface. Roth et al. (1988) found that, in two tillage systems, a 100% residue cover on the soil led to the complete infiltration of a 60-mm rainfall, whereas only 20% of the applied rain infiltrated when the soil was bare.

Tillage can either increase or decrease infiltration rate depending on initial soil conditions. Heard et al. (1988) measured an increase in saturated hydraulic conductivity when soil was plowed, compared with no-till. Although the no-till treatment had similar or fewer total channels, it had the most continuous channels from the 0.10-m depth to the 0.20- or 0.30-m depth. Rotadigging of a plowpan caused a decrease in hydraulic conductivity measured when the soil was near saturation (Kooistra et al., 1984). This decrease was the result of the rotadigging, which left no continuous large pores. Harris et al. (1965) measured an increase in infiltration rate under cotton culture when the number of tillage operations was reduced. According to Quisenberry and Phillips (1978), it is not necessary for the macropores to extend to the surface for flow to occur in them.

The objectives of this study were (i) to determine factors causing high infiltration rates under alfalfa culture and (ii) to determine if these high infiltration rates can be maintained when followed by cotton under either a till or a no-till system.

MATERIALS AND METHODS

The research was conducted at the U.S. Cotton Research Station, Shafter, CA, which is 111 m above sea level and receives an average of 159 mm of rainfall, with little rainfall between May and September. The soil (an Entisol) is a Wasco sandy loam (coarse-loamy, mixed, nonacid Thermic Typic Torriorthent). The amount of shrink-swell is small in this soil.

A nonwinter-dormant alfalfa cultivar, WL514, was planted in 8- by 30-m plots in the fall of 1982 and maintained until early 1988. There were 24 plots with four treatments and six replications in a randomized complete-block design. Plots were irrigated as basins and infiltration rate was determined by measuring water-level decreases with time after flooding. Detailed procedures for the alfalfa experiment are given for 1982 to 1986 in Meek et al. (1989). Only two of the four treatments from the alfalfa experiment were used for this cotton study. The two treatments were (i) loose (no preplant or harvest traffic) and (ii) compacted (repeated harvest traffic applied to 100% of the soil surface after each harvest).

The alfalfa was left unirrigated in 1987 but was harvested twice to remove growth that occurred. The alfalfa was killed on 24 March 1988 by an application of herbicide. The field was irrigated on 31 March. Each alfalfa main plot was subdivided lengthwise into two tillage subplots (each 8 m wide and 15 m long). One of the two subplots was rototilled to the 0.15-m depth on 6 April. The study consisted of 12 main plots with two treatments (traffic or no traffic) divided into 24 subplots by two subtreatments (tillage or no-till) and arranged in a split-block design with six replications. Cotton was planted 18 April, but did not emerge satisfactorily because of cold weather and was replanted 11 May. Emergence was adequate for a normal stand with a plant about every 0.20 m. Cotton was planted in rows 1 m apart using a planter that disturbed a strip 100 mm wide and 50 mm deep for each row. Plots that had been rototilled were cultivated (using sweeps that were 0.46 m wide) on 24 May and 14 July. Plots were irrigated as a basin seven times during the season on 12 May, 16 June, 6 and 20 July, and 1, 11, and 24 August. Plots were irrigated when approximately 50% of the available water was depleted in the top 0.60 m as determined by neutron-probe readings, and sufficient water was applied to refill the soil profile. Ammonium sulfate was applied to the nontilled plots on 29 July (45 kg N/ha) because petiole analysis indicated a N deficiency. No wheel traffic was applied to the plots during the time that cotton was being grown, with all operations being done by a wide tractive frame traveling on wheel paths. Plots were hand weeded as necessary.

The effect of macropores in alfalfa on infiltration was measured from December 1987 to January 1988 by obtaining the water flow rate under fallow conditions at one site in each plot under both ponded and unsaturated conditions. The flow rate under ponded conditions was obtained using the double-ring method (Bouwer, 1986) and the rate under unsaturated conditions obtained using a disk permeameter (Perroux and White, 1988). The difference in flow rate between ponded and unsaturated conditions is assumed to be equal to the flow in the macropores. Watson and Luxmoore (1986) used a similar method to determine flow through macropores.

Measurements under ponded conditions were made by driving an outer and an inner ring into the soil at one site in each plot. The rings were 0.20 and 0.60 m in diameter and were driven to depths of 0.15 (inner) and 0.10 m (outer ring) into the soil. Water levels in the rings were maintained at the same level using inverted bottles with a scale attached to the side. Rate of water flow into the inner ring was measured at 2 h and the infiltration rate calculated.

The disc permeameter was similar to that used by Perroux and White (1988). The water-supply membrane was a stainless steel screen (180-mm diam. with 0.8-mm-diam. apertures). When the measurements under ponded conditions were completed, the water source was removed, and when the water had just infiltrated in both rings 0.25-mm-diam. sand was added to the inner ring to a depth of 30 mm and the disk permeameter was placed in the inner ring. Measurements were made at soil matrix potentials of −0.3 and −0.6 kPa after equilibrium had been reached, usually less than 15 min.

In 1988, infiltration rate was measured for all irrigations except for the germination irrigation on 12 May. Each plot was irrigated as a basin (water was added to approximately the 200-mm depth) and the infiltration determined by measuring the decrease in water level with time. It took 12 to 15 min to flood a plot. Infiltration rates were determined 2 h after one half of the plot was flooded. If all the irrigation water infiltrated before 2 h, the rate at 2 h was calculated by extrapolation. Extra water was added during the last irrigation so that the relationship between infiltration rate and time after water was applied could be defined.

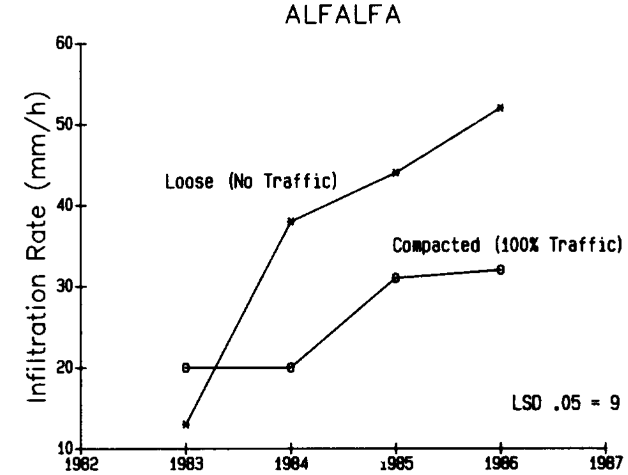

Fig. 1. Infiltration rate under alfalfa culture measured in basins at 2 h after flooding.

For comparison, infiltration rate was measured in a field adjacent to the one in the main experiment. In this field, cotton was planted flat with conventional tillage where barley had been grown the previous year. The bulk density of this field was similar to the loose treatment in the main experiment because operations were done with the wide tractive frame with no wheel traffic allowed in the plots.

Bulk density was measured using a two-probe density gauge, with two measurements in each plot. The procedure used is given in Meek et al., 1988. Soil water potential was measured using tensiometers in 12 of the 24 plots during the irrigation on 16 June (0.15-m depth) and during the irrigation on 24 August (0.10- and 0.20-m depths).

RESULTS AND DISCUSSION

Infiltration Rate—Alfalfa

Infiltration rates increased with time when alfalfa was grown for 4 yr, even when 100% of the soil surface was trafficked after each harvest (Fig. 1). There was a larger increase in infiltration rate for the loose compared with the compacted treatment.

Soil compaction did not significantly reduce total water flow, compared with the loose treatment in this experiment, although the difference was large when measured under ponded conditions with double rings in 5-yr-old alfalfa (Table 1). Compaction reduced water flow by 67% when flow through macropores (>1

Table 1. Infiltration rate on 5-yr-old alfalfa as affected by matrix potential and soil compaction.

Treatment	Matrix potential (kPa)†			Macropore‡
	0.0	0.3	0.6	
	mm/h			
Loose (no traffic)	152	64	51	88
Compacted (100% traffic)	100	21	20	79
Significance	NS	*	*	NS

* Differences within column are significant at the 0.05 level. NS = not significant.

† Soil matrix potentials of 0.3 or 0.6 kPa would have excluded pores of 1 and 0.5 mm, respectively.

‡ Differences in flow rate between flow at 0.0 and 0.3 kPa.

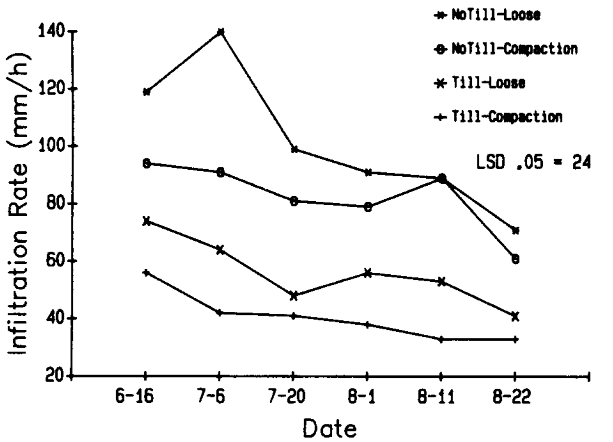

Fig. 2. Infiltration rate under cotton in 1988. Cotton was planted flat and infiltration measured in basins at 2 h after flooding.

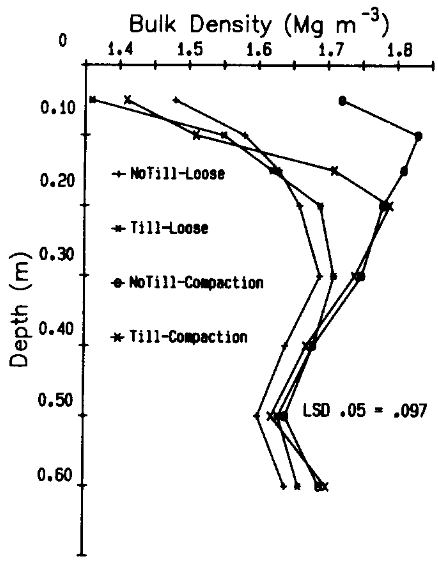

Fig. 3. Bulk density measured in 1988 under cotton culture (each point is an average of 12 readings).

mm) was excluded. The greater difference in flow rates between soil matrix potentials of −0.3 and −0.6 kPa for the loose treatment, compared with the compacted treatment, would indicate more pores in the 0.5- to 1-mm range with no wheel traffic since these are the pores that would drain between −0.3 and −0.6 kPa matrix potential. Traffic did not seem to disturb the flow rate of the macropore system and this allowed water to bypass the compacted surface soil, traveling through macropores.

Infiltration Rate—Cotton

Infiltration rates were high for both no-till treatments, compared with conventional cotton culture (Fig. 2). There was a 40% decrease in infiltration rate from the second to the last irrigation during the season (average of all treatments). Compaction reduced infiltration rate 22%, compared with the loose treatment, and rototilling reduced infiltration by 47% (all treatments and all irrigations). Infiltration rates for the first part of the season under cotton were higher than measured for alfalfa in 1986, indicating a decay of roots during fallow contributing to flow in the macropore system. Mech (1961) reported high infiltration rates under 3rd-yr alfalfa, but the rates dropped drastically under the succeeding potato crop. The difference between the two studies may have been caused by the amount of tillage applied to the potato crop.

In the field adjacent to the main experiment, the infiltration rate measured 2 h after flooding was 12.0 mm/h (11 July) and 13.0 mm/h (11 August). The field was planted flat with cotton and basin irrigated. These rates are similar to the rates measured in grower fields in this area. Barley preceding the cotton crop and conventional tillage between the two crops would have resulted in fewer macropores for water, compared with the deep-rooted alfalfa.

Infiltration rates were high even in the compacted, no-till treatment, which had a bulk density of 1.83 Mg m^{-3} at the 0.10-m depth (Fig. 3). Rototilling the compacted treatment resulted in a decrease in infiltration rate. The rototilling should increase displacement-type water flow through the soil matrix, but would disrupt channels formed by the alfalfa crop.

The decrease in infiltration rate with time after each irrigation was the same for all treatments. When the logarithm of the infiltration rate (cm/min) was plotted against the logarithm of the time after water was applied (min), the slope of the line was −0.349. The uniform slope and same relative differences between treatments with time would indicate that the pore structure was not changing with time as a result of the treatments.

A positive matrix potential was measured near the soil surface both times tensiometer measurements were made. The soil matrix potential at the 0.15-m depth during the second irrigation averaged a positive 1.0 kPa, and only 1 out of 12 readings were negative (Table 2). Readings were similar during the last irrigation, with all tensiometers having a positive matrix potential during irrigation and averaging 1.4 (0.10-m depth) and 1.0 kPa (0.20-m depth). These positive

Table 2. Soil water potential measured during the second (16 June) and last flood irrigation (24 August) of cotton in 1988.

		Loose								Compacted							
		No-till replications				Till replications				No-till replications				Till replications			
Irrigation† no.	Depth	1‡	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.	1	2	3	Avg.
	m	kPa															
2	0.15	1.4	0.5	0.9	0.9	−1.0	2.0	0.7	0.9	0.7	1.9	0.1	0.9	1.5	1.5	0.5	1.2
7	0.10	1.7	1.6	0.6	1.3	1.3	1.1	0.6	1.0	2.6	1.6	2.4	2.2	1.2	1.9	1.3	1.5
7	0.20	1.8	2.0	1.1	1.6	0.7	0.3	0.6	0.5	1.4	1.6	1.9	1.6	0.3	1.3	1.0	0.9

† Reading taken about 36 min after water applied for Irrigation 2 and 90 min for Irrigation 7.
‡ Measurements made in three out of six replications; each value an average of one or two tensiometers.

readings at the bottom of the 0.10- to 0.20-m depth would allow free water to flow into the macropores.

Macropores appear to be effective in conducting water through the soil below the surface layer, even when the surface layer has been rototilled and a row crop planted. The reason is that during flood irrigation a positive head forms at the bottom of the tilled layer because the resistance to flow below the tilled layer is greater than that in the tilled layer. The tilled layer remains loose enough, even late in the cotton season, that a positive head is available to the macropores. Quisenberry and Phillips (1978) also found that, when pores were disrupted by tillage in the upper 0.15 m, deep flow through macropores still occurred.

The depth and size of the alfalfa taproot system produced an extensive macropore flow system and resulted in high infiltration rates when the roots decomposed. No-till or minimum till allowed the macropore system to be preserved and resulted in high infiltration rates when the succeeding crop was grown. Cotton grown following alfalfa (loose soil conditions and no-till) had an infiltration rate after 2 h (11 August) of 89 mm/h, compared with 13 mm/h for cotton grown in an adjacent field (no alfalfa preceding the cotton, loose soil conditions, and conventional tillage).

Additional research needs to be conducted (i) using soils of different textures and soils that shrink and swell and (ii) with applied traffic to determine if the macropore system can be preserved under those conditions.

REFERENCES

Barley, K.P. 1954. Effects of root growth and decay on the permeability of a synthetic sandy loam. Soil Sci. 78:205–210.

Bouwer, H. 1986. Intake rate: Cylinder infiltrometer. p. 825–844. *In* A. Klute (ed.) Methods of soil analysis. Part. 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Carter, L.M., and R.F. Colwick. 1971. Evaluation of tillage systems for cotton production systems. Trans. ASAE 14:1116–1121.

Disparte, A.A. 1987. Effect of root mass density on infiltration among four Mediterranean dryland forages and two irrigated legumes. M.S. thesis. Univ. of California, Riverside.

Edwards, W.M., L.D. Norton, and C.E. Redmond. 1988. Characterizing macropores that affect infiltration into nontilled soil. Soil Sci. Soc. Am. J. 52:483–487.

Gardner, R., and D.W. Robertson. 1954. The beneficial effects from alfalfa in a crop rotation. Colorado Agric. Exp. Stn. Tech. Bull. 51.

Harris, K., L.J. Erie, and W.H. Fuller. 1965. Minimum tillage in the Southwest. Univ. of Arizona Bull. A-39.

Heard, J.R., E.J. Kladivko, and J.V. Mannering. 1988. Soil macroporosity, hydraulic conductivity and air permeability of silty soils under long-term conservation tillage in Indiana. Soil Tillage Res. 11:1–18.

Kooistra, M.J., J. Bouma, O.H. Boersma, and A. Jager. 1984. Physical and morphological characterization of undisturbed and disturbed ploughpan in a sandy loam soil. Soil Tillage Res. 4:405–417.

Mech, S.J. 1961. Soil management as related to irrigation practice and irrigation design. Trans. Int. Congr. Soil Sci., 7th, 1960. 1:645–650.

Meek, B.D., E.A. Rechel, L.M. Carter, and W.R. DeTar. 1988. Soil compaction and its effect on alfalfa in zone production systems. Soil Sci. Soc. Am. J. 52:232–236.

Meek, B.D., E.A. Rechel, L.M. Carter, and W.R. DeTar. 1989. Changes in infiltration under alfalfa as influenced by time and wheel traffic. Soil Sci. Soc. Am. J. 53:238–241.

Moore, I.D. 1981. Effect of surface sealing on infiltration. Trans. ASAE 24:1546–1552, 1561.

Patel, M.S., and N.T. Singh. 1981. Changes in bulk density and water intake rate of a coarse textured soil in relation to different levels of compaction. J. Indian Soc. Soil Sci. 29:110–112.

Perroux, K.M., and I. White. 1988. Design for disc permeameters. Soil Sci. Soc. Am. J. 52:1205–1215.

Proebsting, E.L. 1952. Some effects of long continued covercropping in a California orchard. Proc. Am. Soc. Hortic. Sci. 60:87–90.

Quisenberry, V.L., and R.E. Phillips. 1978. Displacement of soil water by simulated rainfall. Soil Sci. Soc. Am. J. 42:675–679.

Roth, C.H., B. Meyer, H.G. Frede, and R. Derpsch. 1988. Effect of mulch rates and tillage systems on infiltrability and other soil physical properties of an Oxisol in Parana, Brazil. Soil Tillage Res. 11:81–91.

Schuh, W.M., J.W. Bauder, and S.C. Gupta. 1984. Evaluation of simplified methods for determining unsaturated hydraulic conductivity of layered soils. Soil Sci. Soc. Am. J. 48:730–736.

Thomas, G.W., and R.E. Phillips. 1979. Consequences of water movement in macropores. J. Environ. Qual. 8:149–152.

Tisdall, J.M., and H.H. Adem. 1986. Effect of water content of soil at tillage on size-distribution of aggregates and infiltration. Aust. J. Exp. Agric. 26:193–195.

Watson, K.W., and R.J. Luxmoore. 1986. Estimating macroporosity in a forest watershed by use of a tension infiltrometer. Soil Sci. Soc. Am. J. 50:578–582.