

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Publications from USDA-ARS / UNL Faculty

U.S. Department of Agriculture: Agricultural
Research Service, Lincoln, Nebraska

December 1984

Soil Physical Characteristics of Reduced Tillage in a Wheat-Fallow System

L. N. Mielke

Wallace Wilhelm

University of Nebraska-Lincoln, wwilhelm1@unl.edu

K. A. Richards

C.R. Fenster

Follow this and additional works at: <https://digitalcommons.unl.edu/usdaarsfacpub>



Part of the [Agricultural Science Commons](#)

Mielke, L. N.; Wilhelm, Wallace; Richards, K. A. ; and Fenster, C.R., "Soil Physical Characteristics of Reduced Tillage in a Wheat-Fallow System" (1984). *Publications from USDA-ARS / UNL Faculty*. 141. <https://digitalcommons.unl.edu/usdaarsfacpub/141>

This Article is brought to you for free and open access by the U.S. Department of Agriculture: Agricultural Research Service, Lincoln, Nebraska at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Publications from USDA-ARS / UNL Faculty by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Soil Physical Characteristics of Reduced Tillage in a Wheat-Fallow System

L. N. Mielke, W. W. Wilhelm, K. A. Richards, C. R. Fenster

AFFILIATE MEMBER
ASAE

ABSTRACT

SOIL physical characteristics of reduced tillage for fallow-wheat (*Triticum aestivum* L.) were compared for two soils in western Nebraska. The soil physical environment influences the amount of water that enters soil, the availability of water for plants, and the microenvironment important to soil biological processes. Fallow tillage (plow, subtile, no till) did not affect bulk density in Alliance silt loam (fine silty, mixed mesic, Aridic Argiustolls). For Duroc loam (fine silty, mixed mesic Pachic Haplustolls), in which native sod was compared to the above three wheat-fallow tillage methods, numerous effects on soil physical properties were found. Reduced tillage reduced bulk density in the 0- to 76-mm layer. Hydraulic conductivity (H.C.) in the surface 300 mm was greater for native sod than for plowed and subtiled soil. Air permeability (k_a) was lowest and water permeability (k_w) was highest in the native sod. The ratio, k_a/k_w , an indicator of soil structural stability, showed native sod was most stable and the plowed soil was least stable. Infiltration was least for plowed soil, and, after 4 h, infiltration into subtiled, chemical, and native sod was 2.2, 2.4, and 4.7 times greater, respectively. Based on precipitation records and infiltration characteristics, water would seldom run off the surface of these soils.

INTRODUCTION

The primary reasons for tillage in fallow-wheat (*Triticum aestivum* L.) cropping systems are for seedbed preparation and weed control. As winter wheat-fallow cropping systems have been developed over the years, some unique problems have suffered in plant residue management, weed control, water conservation, and soil erosion control. Tillage equipment has constantly been improved and made more versatile, and producers have become increasingly aware of benefits of reduced tillage to crop and soil management.

Fallowing for 14 or more months is a common wheat cropping practice in the Great Plains, where annual precipitation is less than 500 mm. During the fallow period, soil is sometimes left unprotected and is therefore subject to erosion by strong winds and by intense thunderstorms, both of which are common. Fallowing is practiced to accumulate enough soil water to produce a

crop on stored water plus precipitation during the cropping season. Often, more than 75% of the precipitation received during the fallow period is lost in the central Great Plains (Haas et al. 1974). Superior management is required to achieve even a 25% water storage efficiency with a black fallow (plow) crop system. Tilling the soil during the fallow period to control weed growth increases loss of soil water by evaporation.

Within the past century, many different kinds of tillage systems have been developed. Dust mulch was used from the late 1800s to the 1920s to conserve water. Duley and Russel (1942) developed the stubble-mulch fallow tillage system in Nebraska in the late 1930s. Stubble-mulch fallow systems had the advantage of trapping snow, reducing the rate of evaporative water losses, and decreasing runoff and erosion. Fenster et al. (1977) reported stubble mulching, compared to bare soil, resulted in a sixfold decrease in rate of evaporation during the fallow period and nearly a fourfold decrease during the growing season. They also reported wind erosion losses from bare soil exceeded tolerance levels 2 of 8 years, but erosion did not exceed tolerance levels for stubble-mulch tillage in any year. Soil water is also conserved with standing stubble. Greb et al. (1967) in Colorado showed that 66% of snowmelt water was stored in the soil, compared to less than 15% for a July rainstorm.

Stubble-mulch wheat production techniques improved water conservation and soil erosion control. More recently, developments in herbicide technology have provided opportunities to use chemical weed control for fallow, using little or no tillage. When herbicides replaced tillage on fallow land, weed growth was reduced, and soil water storage and grain yield were increased (Wicks and Smika, 1973). Fenster and Peterson (1979) suggested that herbicides may substitute for soil-disturbing tillage operations, which should enhance water storage through decreased evaporation and reduced soil temperature because of more residue on the surface. In addition, surface residue decreases the diurnal fluctuation in soil temperature, which can influence water movement and storage. Residues protect the soil surface from raindrop impact, generally resulting in less runoff and less soil erosion. The purpose of this research was to compare soil physical characteristics of plowed, subtiled (stubble mulch), and nontilled soil in a fallow-wheat rotation and to compare characteristics of tilled soil to soil conditions of a native sod.

MATERIALS AND METHODS

Field Site Description

Two field sites were chosen on the High Plains Agricultural Laboratory located 8.3 km north of Sidney, Nebraska, in the Panhandle of western Nebraska. One soil was an Alliance silt loam, (fine silty, mixed mesic,

Article was submitted for publication in November, 1983; reviewed and approved for publication by the Soil and Water Div. of ASAE in April, 1984. Presented as ASAE Paper No. 81-2022.

Contribution from the USDA-ARS, in cooperation with the Nebraska Agricultural Experiment Station, University of Nebraska-Lincoln. Published as Paper No. 7342 Journal Series, Nebraska Agricultural Experiment Station.

The authors are: L. N. MIELKE, Soil Scientist, and W. W. WILHELM, Plant Physiologist, USDA-ARS; K. A. RICHARDS, Graduate Assistant, University of Nebraska-Lincoln, and C. R. FENSTER, Professor Emeritus, Scottsbluff, NE.

Aridic Argiustolls), with slopes of less than 3.0%. This soil was farmed from 1920 until 1957, then seeded to crested wheatgrass (*Agropyron desertorum* Link) for 10 years. In 1967, the crested wheatgrass sod was moldboard plowed. In 1969, a tillage experiment was initiated, comprising two major blocks (one for fallow and one for wheat) in a wheat-fallow rotation. Fallow treatments studied in this experiment were as follows: plow (no residues on the soil surface), sub till, and no till. The experimental design was a randomized, complete block with a split plot for nitrogen (N) and four replications. No N or 45 kg N/ha was broadcast as ammonium nitrate on the growing wheat in April of the crop year. Plots were 8.5 x 73 m.

Soil at the second site was a Duroc loam (fine silty, mixed mesic Pachic Haplustolls), with slopes of less than 1%. This site remained in native mixed prairie grass sod until 1970 when it was moldboard plowed. The experimental design was similar to that for the Alliance silt loam, except that native sod was maintained as a fourth treatment, plot size was 8.5 m by 45.5 m, three replications were used, and no N variable was included.

Both sites were tilled with conventional field machinery. The plow-fallow treatments were moldboard plowed in the spring, field cultivated two or three times, and tilled with a rotary rod weeder several times before seeding to control weeds and firm the seedbed. The sub till-fallow treatments were undercut with V-blades (0.9- to 1.5-m width) two to four times, and tilled several times with a rotary rod weeder. Initial tillage was at a depth of 100 to 150 mm, with following tillage operations at shallower depths.

In the no-till-fallow system, herbicides were substituted for tillage to control weed growth. Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion), glyphosate [*N*-(phosphonomethyl)glycine], 2,4-D [(2,4-dichlorophenoxy) acetic acid], and dicamba (3,6-dichloro-*o*-anisic acid) were used to control weeds during the fallow period. Details of the weed problems, herbicides used, rates, and timing of application were reported by Fenster and Peterson (1979).

An experimental drill capable of planting in nontilled soil with heavy vegetative residues was used on all treatments. The drill was equipped with 600-mm-diam coulters, chisel point openers for seed, and press wheels, all spaced 300 mm apart. Centurk winter wheat was planted in early September at 50 kg/ha at both sites. Soil tests indicated a need for 40 kg/ha of P, which was applied with the seed only on the Alliance soil.

Field Procedures

Field measurements of the following soil physical characteristics were made: infiltration, mechanical air permeability, water content, and soil strength. All measurements of soil physical properties were made during the cropping period of the crop-fallow sequence, usually during the spring months. Bulk density and hydraulic conductivity (H.C.) were determined in the laboratory on undisturbed field samples. Measurements were sometimes made in both tractor wheel-track and nontraffic areas—wheel track being the tractor track left from the planting operation.

Infiltration of water into the soil was determined by the double-cylinder method (Haise et al., 1956), with a 305-mm-diam inner cylinder driven at least 150 mm into the soil. The 450-mm-diam outer cylinder was driven

into the soil 100 mm. A calibrated Mariotte bottle was used to measure the amount of water entering the soil in the inner cylinder and to maintain a constant water head of 15 mm. The head of water in the inner and outer cylinder was kept about the same to insure vertical water movement into the soil.

Soil strength was measured with a flat-tip, spring-activated penetrometer (Soil Test Inc., Chicago, Ill.)*. The penetrometer was modified with a 305-mm tip extension, which measured the maximum soil resistance of the entire tillage zone to a depth of 300 mm. Soil variability required that six or more measurements be made in the field to obtain valid treatment means. Measurements were made in the wheat row and between the rows. Gravimetric soil water content was determined at time of penetrometer measurement.

Air permeability was determined in the surface 76 mm and the 76- to 152-mm soil depth with equipment described by Grover (1955) and modified by Tanner and Wengel (1957). After air permeability measurements were completed in the field, all air permeability sample cans with intact soil cores contained therein were placed in plastic bags and transported to the laboratory at Lincoln, Nebraska. Sample cans used were 65 mm in diameter and 120 mm in length. Bulk density was also calculated from these samples.

A Uhland sampler was used for determining bulk density of undisturbed soil samples 76 mm in diameter and 76 mm in length, encased in an aluminum cylinder. Soil sampling was in 76-mm-depth increments to a maximum depth of 305 mm.

Laboratory Procedures

Volume of soil and field weight measurements were made on air permeability sample cores. A Dacron polyester fabric was secured over the bottom of the container with a rubber band. Samples were wetted from the bottom for 16 h until satiated as defined by Miller and Besler (1977), and H.C. was determined by the constant head method using tap water. Hydraulic conductivity data were converted to water permeability (Klute, 1965), and air- to water-permeability ratios were determined.

Soil cores in the Uhland sample rings were weighed to determine field water content, cylinders were placed between sealed end plates, and the cores were wet from the bottom for about 16 h until satiated. Hydraulic conductivity was determined by the constant head method using tap water, and bulk density was calculated after oven drying at 110°C.

DISCUSSION OF RESULTS

Generally, more than one measurement of soil physical characteristics is required to understand the hydrologic, chemical, and biological condition of the soil. Tillage directly influences the soil to and beyond the depth of active tillage. Whatever the tillage method, a time lag exists before long-term effects become apparent, which are dependent, to some degree, upon climatic zone, soil, and cropping practice. Fallowing may

*Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Agricultural Dept. or the University of Nebraska-Lincoln and does not imply its approval to the exclusion of other products or vendors that may be suitable.

TABLE 1.
BULK DENSITY OF SOIL UNDER WINTER WHEAT
IN A WHEAT-FALLOW ROTATION NEAR
SIDNEY, NEBRASKA, 1980

Depth	LSD (0.10)	Fallow method			Native sod
		Plow	Subtill	No till	
mm		Mg m ⁻³			
Alliance silt loam					
0-76*	NS	1.25	1.25	1.29	—
76-152†	NS	1.31	1.38	1.30	—
Duroc loam					
0-76*	0.08	1.19	1.10	1.07	0.99
76-152†	NS	1.38	1.34	1.35	1.36

*Average of 12 measurements for the Alliance and 9 for the Duroc soil calculated from air-permeability samples.

†Calculated from Uhland samplers.

lengthen the time lag required for changes in physical properties to be exhibited.

Bulk density of the soil is a gross measure of soil particle consolidation. Normally, tillage loosens the soil, but, if recompacted, bulk density could exceed that of the untilled soil below. Soil bulk density in the 76-mm surface layer of the Alliance silt loam was greater than that of the Duroc for all tillage treatments (Table 1). Bulk density of the Alliance silt loam was not affected by tillage treatment, but in the Duroc loam, bulk density increased as degree of disturbance from tillage increased, especially in the 0- to 76-mm depth (Table 1). Soil bulk densities of soil under sod, no-till, and subtill treatments were very similar at the 229- to 305-mm depth, which was below the tillage zone. Bulk density at 229 to 305 mm for the plowed soil was highest, possibly resulting from the effects of the plow shear plane and tractor wheel track, which was driven in the furrow during plowing.

Saturated H.C. of water through undisturbed soil

cores from the surface 76 mm was greatest for the sod, intermediate for the nontilled and subtilled soils, and least for the plowed soil cropped to winter wheat (Table 2). Hydraulic conductivity generally decreased with depth in the soil; however, the H.C. for sod at the 229- to 305-mm depth was from two to almost four times greater than H.C. for the other tillage treatments. Hydraulic conductivity at the 76- to 152- and 229- to 305-mm depths was greater for no till than the comparable depths for plow and subtill treatments. Wilhelm et al. (1982) observed evidence of tillage planes in all tillage treatments on the Alliance silt loam as indicated by horizontal growth of wheat roots along these planes. A plow plane was still visible in the nontilled soil 12 years after plowing the bromegrass sod. Secondary tillage planes created by the rotary rod weeder were observed in the plow and subtill treatments. Effects of these tillage planes may be only a few mm, and the compaction may not influence bulk density when calculated over 76-mm depth. Smearing and rearrangement of soil particles restrict root penetration and can influence movement of water and gases in the soil. There was no evidence of horizontal restricting layers in the sod and root development was unrestricted.

Penetration resistance (soil resistance, Table 2) through 305 mm was not significantly affected by tillage treatment. The values shown are maximum for the entire depth. Soil resistance is normally lowest when water content is greatest; however, in the native sod, the fibrous nature of root material provided the highest soil resistance.

Water movement into and within the soil depends to some degree on the amount of pore space and the nature of the pores relative to each other. Air permeability is dependent upon pore space and also upon the amount of water in the pores. However, interpretation of air and water permeability data is often difficult because there is a large variation in these measurements; consequently, treatment means appear to be different, but real

TABLE 2. SOIL RESISTANCE, SOIL WATER CONTENT, BULK DENSITY, AND HYDRAULIC CONDUCTIVITY AS AFFECTED BY FALLOW METHOD NEAR SIDNEY, NEBRASKA, DUROC LOAM SOIL CROPPED TO WINTER WHEAT, MAY 14, 1980

Fallow method	Depth	Soil resistance	Water content	Bulk density	Hydraulic conductivity
	mm	kPa	m ³ m ⁻³	Mg m ⁻³	mm-h
Plow	0-76	1658*	0.290	1.20†	19.4†
	76-152		0.228	1.38†‡	15.4†‡
	229-305		0.184	1.44†‡	12.5†‡
Subtill	0-76	1776	0.301	1.10	33.0
	76-152		0.241	1.34	10.1
	229-305		0.229	1.33	8.9
No till	0-76	1806	0.386	1.07	32.0
	76-152		0.191	1.35	21.9
	229-305		0.185	1.34	23.2
Native sod	0-76	2031	0.389	0.99	110.5
	76-152		0.264	1.36	73.0
	229-305		0.227	1.35	44.0
LSD (0.05)	0-76	NS	0.047	0.08	NS
	76-152		NS	NS	NS
	229-305		NS	NS	16.0

*Maximum resistance for 0- to 305-mm depth.

†Average of nine measurements on air-permeability samples for 0- to 76-mm depth for all treatments.

‡Measured on Uhland sampler for 76- to 152- and 229- to 305-mm depths for three replications for all treatments.

TABLE 3. AIR PERMEABILITY (ka), WATER PERMEABILITY (kW), AND ka/kW RATIO FOR TWO SOILS AND NATIVE SOD AS AFFECTED BY FALLOW METHOD, SIDNEY, NEBRASKA, MAY 1980

Fallow method	Alliance silt loam				Duroc loam			
	ka	kW	ka/kW	Water content	ka	kW	ka/kW	Water content
	μm^2	μm^2		$\text{m}^3 \text{ m}^{-3}$	μm^2	μm^2		$\text{m}^3 \text{ m}^{-3}$
Plow	11.6	0.50	33	0.28	3.5	0.55	21	0.29
Subtill	4.1	0.39	20	0.28	2.9	0.94	11	0.30
No till	2.8	0.14	27	0.30	2.8	0.91	11	0.39
Native sod	—	—	—	—	1.8	3.41	5	0.39
LSD (0.10)	NS	0.26	NS	NS	NS	NS	3	0.05

differences may not exist. Such was frequently the case with data presented in Table 3. Soils with least water exhibited greatest air permeability, as expected. The ratio of air to water permeability is indicative of the structural stability of soil. Actually, all ratios were small, which indicates a very stable structure for both cropped soils. Differences in the air-to-water permeability ratios among tillage treatments were not significant for the Alliance silt loam, but were significant for the Duroc loam. Plowed soil usually had the highest ratio, or least stable structure, with intermediate ratios for the subtilled and nontilled soils, and lowest ratio for sod. Thus, structural stability, as indicated by air- to water-permeability ratios, increased as intensity of soil disturbance by tillage decreased.

Air permeability of wheel track of the Alliance soil was generally less than for the nontraffic areas. Wheel traffic generally increases bulk density and decreases pore space and continuity of pore structure. Nitrogen fertilizer influenced air permeability, but the trends were not consistent between tillage treatments.

When precipitation is limited, water infiltration into the soil is critical to provide soil water for crop production. Plant residues on the soil surface reduce surface sealing, decrease runoff water loss, and reduce evaporation losses; however, once water enters the soil, physical characteristics of the soil beneath determine how rapidly water is distributed in the soil profile. Infiltration combines all the positive and negative physical soil properties into one measurable characteristic. However, surface infiltration may be greater than the rate of water redistribution in a restricting zone within the soil. Surface retention of precipitation that keeps water from running off until infiltration occurs is beneficial when zones within the soil restrict water movement to rates less than that of the infiltration rate.

For plow and subtill, cumulative infiltration after 4 h was about the same in the fall for the wheel-track and

TABLE 4. CUMULATIVE INFILTRATION OF WATER INTO CROPPED SOIL AFTER 4 HOURS AS AFFECTED BY FALLOW METHOD FOR ALLIANCE SILT LOAM NEAR SIDNEY, NEBRASKA

Fallow method	Fall 1977 (Oct. 12)		Spring 1978 (Mar. 28)
	Wheel track	No wheel track	No wheel track
	mm	mm	mm
Plow	45	52	55
Subtill	47	44	113
No till	159	150	98
LSD (0.10)	NS	41	NS

nontraffic areas for Alliance silt loam (Table 4). Infiltration for the nontilled soil was about three times greater than for the other tillage treatments. Changes in infiltration for nontraffic soil the next spring were not consistent, increasing slightly for plowed, doubling for subtilled, and decreasing almost one-third for no-till-fallowed soils when cropped to wheat. Infiltration trends changed for subtill and no till from the fall of 1977 to spring 1978. In May 1980 (Table 3), the trend of kW for Alliance soil was reversed for the tillage treatment compared to 1977 infiltration data. Infiltration and permeability measurements are greatly influenced by the soil conditions that are subject to change with time of year.

We hypothesized that, after 10 years, there would be an effect of tillage and fertilizer treatment on infiltration and other physical characteristics. If there were different amounts of root mass developed, for example, the infiltration characteristics of the soil might be affected. Wilhelm et al. (1982) reported greater amounts of root material in nontilled soil on this site. While tillage method influenced root development generally, grain yields have not been greatly affected by tillage method (Fenster and Peterson, 1979). However, there was no apparent influence of N fertilization on water infiltration into Alliance silt loam in spring 1979 (Table 5); likewise, there were no effects of tillage on infiltration. Crop yields have varied from year to year as a result of weather (including effects of hail damage) and other factors, such as weed and insect competition.

Infiltration of water for tillage treatments used on cropped Duroc loam was different for each time (0.5 to 4.0 h) interval (Fig. 1). At 0.25 and 0.5 h, infiltration was

TABLE 5. INFILTRATION OF WATER INTO CROPPED SOIL AS AFFECTED BY FALLOW METHOD AND NITROGEN FERTILIZATION FOR ALLIANCE SILT LOAM NEAR SIDNEY, NEBRASKA, MAY 22, 1979

Fallow method	N fertilization kg ha^{-1}	Hours				
		0.5	1.0	2.0	3.0	4.0
		mm	mm	mm	mm	mm
Plow	0	41	53	72	87	101
	45	38	50	65	88	104
Subtill	0	40	49	67	79	92
	45	47	57	67	79	92
No till	0	60	73	96	116	129
	45	39	50	70	88	104
LSD (0.10)		NS	NS	NS	NS	NS

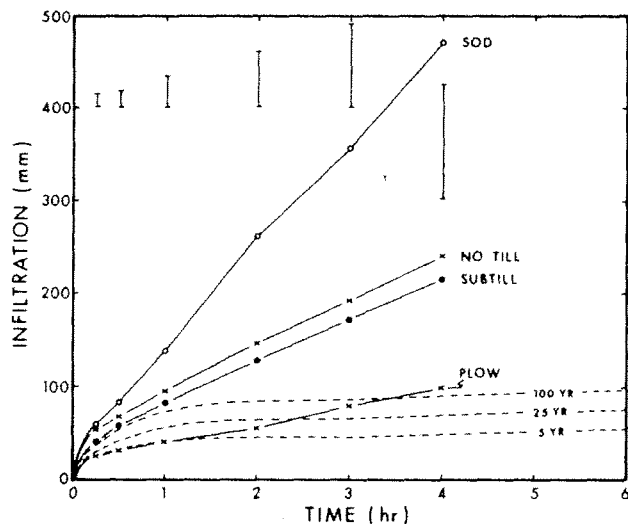


Fig. 1—Cumulative infiltration for fallow tillage methods for Duroc loam near Sidney, Nebraska, compared to precipitation amounts for 5-, 25-, and 100-year return frequency. Bars are proportional to $LSD_{(0.10)}$ values.

greatest for the no-till and native sod treatments. Infiltration into native sod was very rapid and maintained a nearly constant high rate throughout 4.0 h. Hourly ratio and total amount infiltrated into subtill and no-till treatments were more than double the values for the plow treatment. Air permeability samples were used to determine H.C. for the 0- to 76-mm depth presented in Table 2. Field conditions preceding this sampling date were normal for the season, with a complete canopy of wheat about 300 mm high. The 48 h preceding sampling were cloudy and cool (low of 5°C and high of 16°C) with 15 mm rain and snow. In spite of this precipitation, there was greater water content in the 0- to 76-mm depth of nontilled and native sod soils than for plowed and subtilled soils.

Data in Fig. 1, taken from the U.S. Department of Commerce (1961), show the amount of precipitation that can be expected in the Panhandle of Nebraska for 0.5 to 6 hours' duration on a 5-, 25-, and 100-year frequency. Infiltration rates shown in Fig. 1 can be compared to probable precipitation return time in years. For example, infiltration into the plow treatment after 0.5 h for the Duroc soil was 31 mm, which falls between the 5- and 25-year rainfall frequency with a 0.5-h duration. Infiltration for the subtill and no-till treatments exceeded the 100-year frequency for the 0.5-h duration, suggesting that, in this climate, tillage methods would affect amount of water lost by runoff in no more than 1 year out of every 5 or more years. Possibly this is part of the reason why differences in crop yields were seldom found between tillage treatments. Even with its slower initial intake rate, the plowed soil can take in most of the

rain. Historical records show most of the annual precipitation comes as small events. In 1979, for example, there were only four 24-h periods when precipitation exceeded 18.0 mm, and only one such event in 1980.

Water intake during the first 0.5 h was fairly high and about the same for the tillage treatments on Alliance and Duroc soils. After 1 h, the rate for no till and subtill was about the same (Fig. 1), while plow was less. Native sod maintained the highest rate throughout and was higher than the other tillage treatments at 1 h through 4 h. The effects of tillage on infiltration compared to native sod are illustrated in Fig. 1.

The data illustrate the effects of time and space on infiltration. Table 4 contains data for fall after planting, where cumulative infiltration after 4 h was greatest for no till (nontraffic) and spring for the same plots. However, the data for Table 5 were from a companion set of fallow plots about 15 m away. The cumulative amount infiltrated in 4 h for plow in the latter case was about twice that of the other set of plots. In fact, the 1-h amount was about equal to the final amount at 4 h.

References

- Duley, F. L., and J. C. Russel. 1942. Machinery requirements for farming through crop residues. *AGRICULTURAL ENGINEERING* 23(1):39-72.
- Fenster, C. R., H. I. Owens, and R. H. Follett. 1977. Conservation tillage for wheat in the Great Plains. PA-1190 USDA Ext. Ser.
- Fenster, C. R., and G. A. Peterson. 1979. Effects of no-tillage fallow as compared to conventional tillage in a wheat-fallow system. Res. Bull. No. 289, Univ. of Nebr.-Lincoln.
- Greb, B. W., D. E. Smika, and A. L. Black. 1967. Effect of straw mulch rates on soil water storage during the summer fallow period in the Great Plains. *Soil Sci. Soc. Am. Proc.* 31:556-559.
- Grover, Ben L. 1955. Simplified air permeameters for soil in place. *Soil Sci. Soc. Am. Proc.* 19:414-418.
- Haas, H. J., W. O. Willis, and J. J. Bond. 1974. Summer fallow in the Western United States. Cons. Res. Rep. No. 17. USDA-ARS, Washington, D.C.
- Haise, H. R., W. W. Donnan, J. T. Phelan, L. F. Lawhon, and D. G. Shockley. 1956. The use of cylinder infiltrometers to determine the intake characteristics of irrigated soils. ARS Series 41-7. USDA-ARS.
- Klute, A. 1956. Laboratory measurement of hydraulic conductivity of saturated soil. p. 210-222. In: C. A. Black (ed.) *Methods of Soil Analysis, Part 1, Agronomy 9*. Am. Soc. Agron., Madison, Wisconsin.
- Miller, R. D., and E. Besler. 1977. A quick method for estimating soil water diffusivity functions. *Soil Sci. Soc. Am. J.* 41:1020-1022.
- Tanner, C. B., and R. W. Wengel. 1957. An air permeameter for field and laboratory use. *Soil Sci. Soc. Am. Proc.* 21:662-664.
- U. S. Department of Commerce, Weather Bureau. 1961. Rainfall frequency atlas of the United States. Technical Paper No. 40. 61 pp, U.S. Govt. Printing Office, Washington D. C.
- Wicks, G. A., and D. E. Smika. 1973. Chemical fallow in a winter wheat-fallow rotation. *Weed Sci.* 21:97-102.
- Wilhelm, W. W., L. N. Mielke, and C. R. Fenster. 1982. Root development of winter wheat as related to tillage in Western Nebraska. *Agron. J.* 74:85-88.