An infiltration study on Montana soils
by George A Reichman

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree Of Master of Science in Soils
Montana State University

Abstract:
Infiltration rates were measured in the field on 21 soil types located in eight different irrigated farming districts in Montana during the summer of 1950. The infiltration rates of the soils of similar parent material were found to be related to rainfall.

Different average infiltration values were found for the different soil types, even though the variability among replicate determinations was high. The data fits the formula: accumulated infiltration = b(time)^a.

For surface soils the infiltration rates were directly proportional to the clay content and inversely proportional to the sand content. The surface infiltration rate decreased between the spring and fall measurements. The data show a tendency for the infiltration to be directly proportional to the ground cover of each crop.

Lateral movement of water after passing the metal ring was about 2/3 as rapid as vertical movement. The relationship between volume weight and infiltration on soils of similar parent material appeared to follow the form: log infiltration rate = 5.7((1/volume weight)-.714). No relationship between the initial moisture content and infiltration was found.

According to the disturbed sample data, the surface rates of the sandy loams exceeded the subsurface rates, while the reverse was true of the silt loams. The permeabilities of saturated undisturbed cores was related to the field infiltration rates. The pore space drained at low tensions decreased between spring and fall and parallels the infiltration change.

It is concluded that the unbuffered ring will measure relative infiltration values that may be corrected by a mathematical treatment to approximate true infiltration values. Attempts to relate laboratory techniques and field observations on infiltration were only moderately successful.

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ABSTRACT

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Different average infiltration values were found for the different soil types, even though the variability among replicate determinations was high. The data fits the formula: accumulated infiltration $= b(\text{time})^a$. For surface soils the infiltration rates were directly proportional to the clay content and inversely proportional to the sand content. The surface infiltration rate decreased between the spring and fall measurements. The data show a tendency for the infiltration to be directly proportional to the ground cover of each crop.

Lateral movement of water after passing the metal ring was about 2/3 as rapid as vertical movement. The relationship between volume weight and infiltration on soils of similar parent material appeared to follow the form: $\log \text{infiltration rate} = 5.7 \left(\frac{1}{\text{volume weight}} - .714 \right)$. No relationship between the initial moisture content and infiltration was found.

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INTRODUCTION

An important characteristic of soil is the rate at which it will absorb water from rains, runoff or flood irrigation. With a knowledge of infiltration rates it is possible to devise soil management practices which will minimize erosion and flood hazards and contribute to efficient water use.

The measurements of infiltration that have been made previously are limited in scope, quantity and usefulness. An infiltration study was undertaken to collect data representing an extensive part of Montana, and to measure the variability encountered at each location.

Additional objectives were: (1) to obtain a measure of the reliability of an unbuffered ring procedure for measuring field infiltration and (2) to evaluate laboratory techniques in relation to field techniques.

Soils were selected to represent dominant types in the important irrigated valleys. A location was chosen that represented each soil type, and the infiltration rate was determined. Other physical properties were measured and the cropping history recorded.

On the soils conveniently located near Bozeman, additional samplings were taken for supplemental laboratory tests. These tests included permeability measurements, determinations of volume weight and pore size distribution of the soils.

LITERATURE REVIEW

Water and air movement into the soil have been recognized as important physical properties. Baver (2) cites studies of these soils properties extending back about a century.

Free, et al., (15) determined relative water infiltration values on sixty-eight different soil types. The range in values was from .05-5.00 inches per hour. Other workers who have made water infiltration studies on various soil types include Lewis (19) and Musgrave (22). Duley and Kelly (12) determined that at the end of 1.5 hours the infiltration rates on clay loam, sandy loam, silt loam and silty clay loam had a range from 0.16"/hour to 0.33"/hour.

Auten (1) compared the infiltration rates of surface soils to the rates of subsurface soils and found that under forest cover the subsoil was the slower, whereas on cultivated fields he did not find differences.

Lewis (19) found that his infiltration data could be expressed by an equation of the form $I = bt^a$, where "I" is accumulated infiltration, "t" is elapsed time, "a" and "b" are coefficients. According to Phillips (26) this equation was first used by Kostiakov. Lewis points out that the first differential of this equation is the form used to calculate the rate of infiltration at any desired time. This results in the form $i = abt^{a-1}$ in which i is rate in inches per minute, t is minutes from start of infiltration, and a and b have the same values as in the original equation. This analysis compliments Free, et al., (15) who found that the infiltration rate at one interval was a good estimate of the infiltration rate at any other interval.

The influence of season on infiltration rates is mentioned by Beutner, et. al., (3) who connected lower rates with cooler months. Horton (16) gives the following reasons for differences in seasonal infiltration: (1) cultivation increases infiltration rates, (2) active soil fauna help to increase the infiltration rate and (3) the infiltration rate on sandy soils follows the temperature closely.

Forest litter or other soil cover will prevent clogging soil pores with suspended silt in runoff water according to Lowdermilk (21). Lewis and Powers (20) observed a much greater intake of water into native sod than into eroded, tilled land. Musgrave and Free (23) observed that dense vegetation prevents the sealing of the surface that occurs on bare fallow or desurfaced soil as water is repeatedly applied.

To determine the extent of lateral water movement in soils, Free, et al., (15) made several types of determinations. Soil samples were taken outward from 4 feet by 6 feet plots which were sprinkled by a rain similator. While Free's data is not specific with regard to the elapsed time during which lateral movement was measured, it is evident that a movement of at least 12 inches beyond the wetted area was encountered. Movement did not at either depth extend out 36 inches during the time of observation.

Tensiometers were set at plot center and 6 inches and 30 inches from the side of the plot and the time between flooding and rapid drop of instrument reading was recorded. The tensiometers 30 inches from the plot at a depth of 7 inches recorded increased moisture content about 1 hour after water was applied to the plot. In highly permeable Honeoye soil using a tube infiltration technique, Free, et al., (15) state, "water about 8 inches below the tube was found to have spread laterally about 40 inches".

Lewis (19) found infiltration rates for 1/6 A. plots were comparable to infiltration rates for 18 inch rings. The rate of infiltration into a tube set 7 feet into the soil was as rapid as those set only 3 or 4 inches. In neither study did lateral movement seriously influence the accuracy of the determination. When a six inch ring was surrounded by a buffer strip within an 18 inch ring and both set 3 inches into the soil, the rate was greater from the buffer strip than from the center ring. Lewis measured no difference in rates when both rings were set 6 inches into the soil.

Extremes in initial moisture content affected the infiltration rate of Chehalis loam as measured by Lewis (19). Free, et al., (15) list initial moisture content among those variables they did not measure. Musgrave and Free (23) suggest that there may be a moisture content below which the infiltration rate is little affected by the initial moisture percentage.

Nelson and Baver (24) measured mixtures with known pore space arrangements constructed from sand separates and state that percolation varied directly with the amount and inversely with the size of pores. Musgrave and Free (23) came to the conclusion that increasing the pore space by cultivation increased the rate of infiltration. The data of Free, et al., (15) show a significant correlation between non-capillary porosity and infiltration.

Several types of equipment have been used in the field to measure infiltration. Simple rings set only a few inches in the soil have been used by Evanko (13), Kirby (17) and Auten (1). Others have added a buffer strip of water outside this type of ring. Free, et al., (15) and Musgrave (22) are among those who have forced tubes into the soil 6 inches or more to confine the infiltering water. A rain-similator or sprinkler type of equipment has been used by Horton (16), Duley and Kelly (12), Free et al., (15) and others.

To make possible precise descriptions of various phases of water movement studies in soils Richards (26) has presented a series of technical definitions, among which were these: Infiltration (soil). The downward entry of water into the soil. Infiltration capacity or infiltration rate (soil). The maximum rate at which a soil, in a given condition, at a given time, can absorb rain, or will absorb water impounded on the surface at a shallow depth when adequate precautions are taken regarding border and fringe effects. Permeability (soil). (1) Qualitative. The quality or state of a porous medium relating to the readiness with which such a medium conducts or transmits fluids. (2) Quantitative. The specific property designating the rate or readiness with which a porous medium transmits fluid under standard conditions.

The soils that were studied had been surveyed and mapped and the descriptions of these soils can be found in the following references: (4), (6), (7), (8), (9), (10), (11), and (25).

MATERIALS AND METHODS

Field infiltration studies were made on important soil types as selected from soil survey maps for several widely distributed irrigated areas of Montana. Data was obtained on thirty-three sites comprising 21 soil types.

The equipment for determining field infiltration consisted of a ring to impound water on the surface of the soil and a supply of water. The ring was constructed of one eighth inch sheet iron about nine inches in diameter and six inches high. Metal grips were welded to the sides of the ring to aid in setting. A scale was painted on the inside of the ring to facilitate measuring the depth of the water. Two rings had large saw-like teeth while the other two had smooth sharpened edges. The soil condition determined which type of ring could be most easily set.

The small size of the ring made for high variability among measurements had already been found by Free, et al., (15). However, for this survey type of information ready mobility of equipment was essential. This necessitated hauling water to the field in a barrel and consequently the size of ring used had to be such that the barrel provided adequate water to complete a measurement. Local canals were the usual source of water. At each site a ring was set into the soil sufficiently deep to retain water. A cheese cloth and wood barrier was used to prevent disturbance of the surface soil while water was being added to the ring. Water was poured into the ring to a depth of approximately two and one-half inches. The infiltration rate was determined by recording the time required for half inch increments of water to be taken into the soil.

Water was added as required to keep the water surface between $\frac{1}{2}$ and $2\frac{1}{2}$ inches about ground level. The observations were recorded for at least three hours or until at least 12 inches of water had entered the soil.

At each site four replications were secured by setting rings on the soil surface, taking precautions to prevent soil disturbance. In addition the soil was removed from two sites to a depth of 4 to 6 inches to determine subsurface infiltration. The soil was carefully removed to approximately the desired depth with a hand shovel so that the exposed surfaces consisted mostly of aggregate surfaces exposed along natural lines of weakness between macrostructural units. This surface was left slightly rough to insure against a glazed condition. The ring was set into this surface with a minimum of movement and any clods loosened in this operation were removed. Infiltration rates were determined on these subsurface sites as outlined above for surface soils.

For volume weight determinations, samples of know volume were secured by driving a calibrated 3 inch tube into the soil to the appropriate depth. No attempt was made to retain the natural structure in the sample when it was removed from the tube but the entire sample was packaged and taken to the laboratory. After drying and weighing, the volume weight of the soil was calculated. The volume weight samples for the 0-3 and 3-6 inch depths were secured within about 12 inches of each infiltration site. At the sites where subsurface infiltration rates were determined two additional volume weight samples were taken representing depths of 6-9 and 9-12 inches.

At each surface infiltration site moisture samples were secured to represent the 0-6 inch layer. A 6-12 inch moisture sample was also taken where subsurface infiltrations were determined.

For laboratory studies a distrubed sample of soil was secured in the autumn from each infiltration site in the vicinity of Bozeman, representing the 0-6 and 6-12 inch layers. On each sample the relative permeability was determined using Fireman's (14) method. A second part of the sample was used to determine the pore space distribution on the pressure plate apparatus at tensions of 10, 20, 60, 100, 345, and 1000 cm. of water. The method has been described by Richards and Fireman (28). Similarly undisturbed cores were collected from each Bozeman site to represent the 0-6 and 6-12 inch layers. Uhland and O'Neals (30) method was used to take the samples and to determine initial and saturated permeability and the corresponding non-capillary pore space in addition to the volume weight of the samples.

Statistical analysis used for table VI was according to methods described by Snedecor (29).

EXPERIMENTAL RESULTS

Field Studies

The general location of the infiltration sites and the dates on which field observations were made are presented in table I. This table also lists the figures which present supplemental data for each general location of sampling sites.

Table I. Summary of different sampling sites, approximate dates of infiltration measurements and figure numbers providing detailed data.

Location	Dates of Measurement	Figures Providing Detailed Data
Bozeman	June 15 - July 8, 1950	11 - 20
do	Sept. 28 - Oct. 16, 1950	21 - 26
Corvallis	Aug. 14, - 15, 1950	27 - 28
Ronan	Aug. 8 - 10, 1950	29 - 30
Creston	July 31 - Aug. 3, 1950	31 - 33
Conrad	Aug. 28 - 30, 1950	34 - 35
Chinook	Aug. 24 - 26, 1950	36 - 37
Fairfield	Aug. 31 - Sept. 8, 1950	38 - 39
Miles City	July 12 - 20, 1950	40 - 43

The legal description of each location is listed in table VII of the appendix.

Infiltration data on the soils near Bozeman were secured early in the season on the sites represented by figures 11-20. A second set of data which was obtained in the fall is presented in figures 21-26, from sites adjacent to those used to obtain the data for figures 11-16.

The infiltration data from pasture or native range near the sites represented by figures 13-15 is presented in figures 18-20.

Additional infiltration data was collected from the other areas in the state during the summer season and is presented in figures 27-43.

Infiltration is one of the most variable properties of the soil and considerable variation occurs in the different replications of the data at each site. However, the infiltration rates for soils in the Bozeman area appeared to vary through a greater range than did infiltration rates for the other soil areas investigated. Subsurface samples appeared to be about as variable as surface samples.

Table VIII, appendix, presents the average rate of infiltration over the first two hour period in inches per hour. In three cases one value varied excessively from the other values and was ignored in calculating averages. A value was ignored when it either exceeded by four times or was less than one quarter of the average of the other three values. The soil types on which the average is calculated from three values are Bozeman silt loam, Huffine silt loam and Creston silt loam.

Reference to figures 11 to 43 shows essentially two parts to the infiltration rate curves. During the first few minutes of the determination, the infiltration rate changes rapidly with time. While this conditioning period differs for the different sites, it does not ordinarily exceed the first 15 minutes of the observation. After this initial period the relationship between time and cumulative infiltration approaches a straight line. Since this latter portion of the curve for the different replications at a site differ in slope it is apparent that the soils differ in properties which contribute to the sustained infiltration rate.

The variation associated with distances of 10 miles and 200 miles respectively was insignificant in the data from Manhattan very fine sandy loam (figures 16, 17, and 26) and Havre silt loam (figures 37 and 41).

The data for four soils in which all replications had infiltration rates exceeding five inches per hour are graphed in figures 31, 32, 33 and 38. In figures 14, 18, 19, 27, 29, 30, 31, and 39, the data for each replication of the surface soils at the site shows infiltration rates exceeding that of any subsoil infiltration rate at that site. In figures 20, 22, 25, 28, 34, 36, 40, 42, and 43, the reverse is true; whereas, in the other 16 sites the data for surface soils and subsoils overlap.

The data from four replications were selected to study the applicability of Kostiakov's (26) equation, $I = b\ t^a$, to the infiltration values obtained in this study. The curves of this equation were fitted by trial and error to the selected data and presented in figures 1-4.

The infiltration data in figure 1 from Havre silt loam was selected as the slowest and is compared to the curve of the formula $I = .0737t^{.7}$. The low infiltration rate is indicated by the low value of coefficient "b". Similarly the high infiltration rate of Huffine silt loam and the high value of coefficient "b" are shown by figure 2.

Figure 3 is a comparison between the infiltration curve of Bozeman silt loam, on which the infiltration rate changed most rapidly with time, and the curve of the equation $I = .6t^{.58}$. The infiltration data for Manhattan very fine sandy loam fits the curve of the formula $I = .187t^{.8}$ as shown in figure 4. In this figure the change in rate of infiltration with time is the lowest encountered in the study. In the equation, the