The Effect of Rainfall Energy on Water Infiltration into Soils[1]

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Abstract

Simulated rain was applied in the field to seven Indiana soils ranging in texture from a sand to a silty clay. Each site was divided so that one half of the plot was bare fallow while the other half was protected by a layer of screenwire suspended 10 cm above the surface. A comparison of the infiltration characteristics of these soils under these two conditions when exposed to high energy rain showed rainfall energy to be the principal causative factor in surface sealing. The magniture of these differences was greatly influenced by soil texture, however, medium textured soils were affected most severely. After 30 minutes of rainfall, infiltration rates on medium textured, bare soils were 20 to 30% of those on protected soils.

The formation of a layer at the soil surface that reduces water intake has been recognized for over a century (1). The principal factor responsible for the formation of this surface seal has been shown to be the impact of raindrops on the soil surface (5). Duley and Kelly (2), for example, showed that when the surface was protected by cover, a broad range of infiltration rates occurred between different soil types. The differences diminished, however, when these same soils were bare and subjected to rain. Other workers (3,7) have reported permeabilities for surface seals of 1/5 to 1/2000 of those of underlying materials. In the solution of a mathematical model, Swartzendruber (6) showed that the conductivity of the least permeable layer does not of itself control flow but is dependent on the physical characteristics of both the least permeable layer and the other material in the system.

Although much effort has been directed to understanding water intake into sealed soil surfaces, the magnitude of changes in infiltration rates of Indiana soils brought about by rainfall energy remains unsolved.

It is the purpose of this study to show the accumulative influence of rainfall energy on infiltration rates for a wide range of soil textures.

Methods and Procedures

Infiltration rates were determined by using the rainfall simulator described by Meyer and McCune (4). Two storms of 1-hour duration at an intensity of 7.0 $\pm$ 0.5 cm per hr were applied on successive days to soils that had been maintained in a fallow condition for several months. Two treatments or conditions were used to measure the influence of high energy rainfall on infiltration rates of fallow (bare) soils: 1) rainfall of high kinetic energy was applied to a bare, unprotected soil,

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and 2) rainfall with low kinetic energy was applied to this same soil. This was accomplished in the following manner. Prior to the application of simulated rainfall, one plot (12 x 35 feet in size) was covered with a double-layer of 18 x 14 mesh screenwire. This screenwire was suspended 10 cm above the soil surface to reduce drop size and velocity (kinetic energy) of the rain without obstructing overland flow or runoff. A second adjacent plot was left bare and unprotected.

This study was conducted on seven Indiana soils (Table 1) ranging in texture from a sand to a silty clay. Some of the relevant soil properties are shown in Table 1.

TABLE 1. *Properties of soils tested.*

	Sand (%)	Silt (%)	Clay (%)	Organic Matter (%)	Aggregation Index
Oakville sand	94	4	2	0.5	0.065
Fox gravelly sand loam	80	12	8	1.1	0.181
Warsaw sandy loam	62	25	13	3.3	0.408
Fox silt loam	22	57	21	1.3	0.494
Zanesville silt loam	9	72	19	1.3	0.160
Cincinnati silt loam	9	72	19	1.3	0.205
Markland silty clay	4	55	41	3.9	0.986

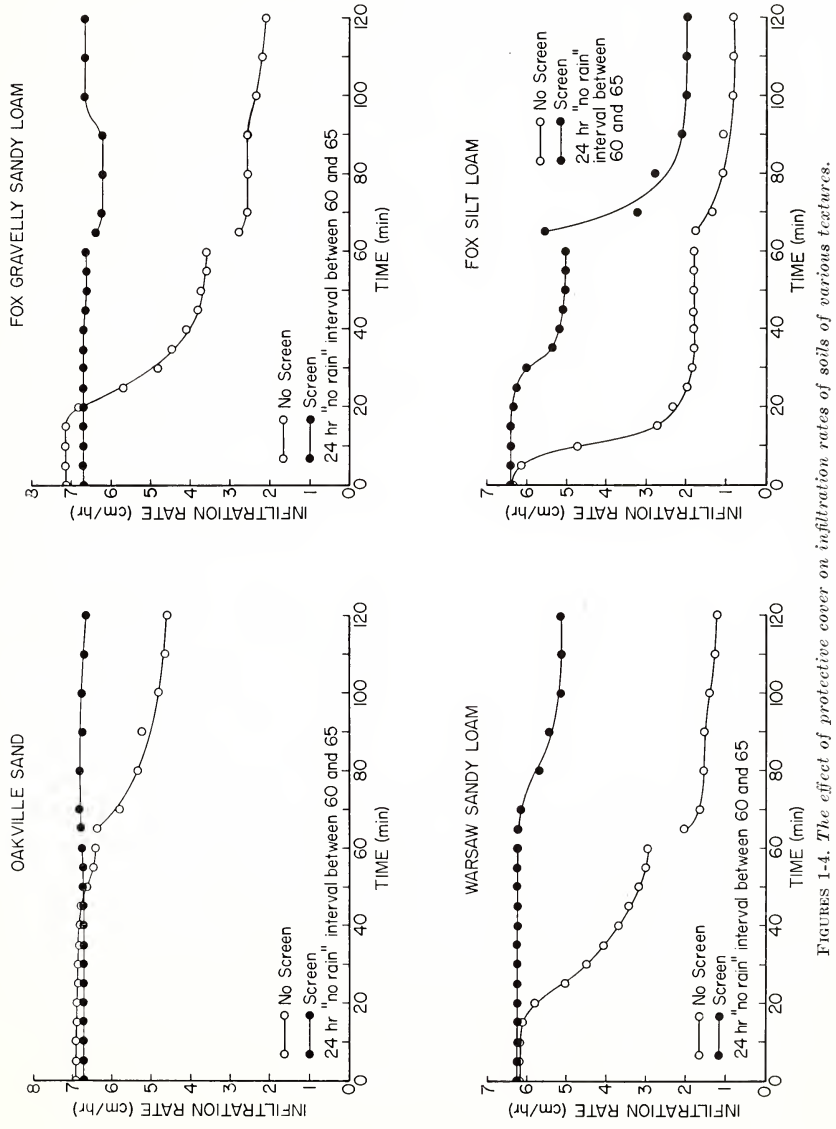
The kinetic energy of the rainfall from the simulator is approximately 800 ft tons per acre inch (4). The kinetic energy of the same intensity rainfall falling through a double-layer of screenwire is not known. However, it has been observed by means of high-speed photography that the screenwire effectively disperses large drops. As a consequence, the rainfall energy of single drops is expended over a much larger area and the velocity of a sizable portion of the falling drops is reduced. Both of these factors would greatly reduce the kinetic energy of the falling rain and, therefore, its dispersive power in the formation of surface seals.

Results and Discussion

The effects of the rainfall energy on infiltration rates of the various soils over a 2-hour period are shown in Figures 1 through 7.

The protective screenwire is shown to have very little influence on the infiltration on the Oakville sand during the first 60-minute storm (Fig. 1) since on both the protected and unprotected plots essentially all of the rain applied entered the soil. This was true for the protected plot throughout the 2-hour storm. However, the infiltration on the bare plot was reduced to 70% of that on the protected plot at the end of 2 hours.

More evidence of surface sealing occurred on the Fox gravelly sandy loam (Fig. 2) when the protective cover permitted essentially all water applied during the 2-hour storm to enter the soil. On the other hand, infiltration rates on the unprotected plots were only 55% and 32%, respectively, of that on the protected plots at the end of 1 and 2 hours. The formation of the surface seal on the bare plot had largely occurred



Figures 1-4. *The effect of protective cover on infiltration rates of soils of various textures.*

after only 20 minutes of rain as evidenced by the rapid drop in infiltration rate.

Figure 3 shows the effect of rainfall energy on the infiltration rate of a Warsaw sandy loam. Again, the infiltration rate remained high on the protected plot throughout the 2-hour test while the infiltration rate on the sealed plot had decreased 48% and 24%, respectively, at the end of 1 and 2 hours. Although the soils studied in Figures 2 and 3 are both sandy loam in texture, the Warsaw soil had approximately twice the silt + clay content of the Fox soil which probably accounted for the appreciably lower infiltration rate at the end of the 2-hour storm.

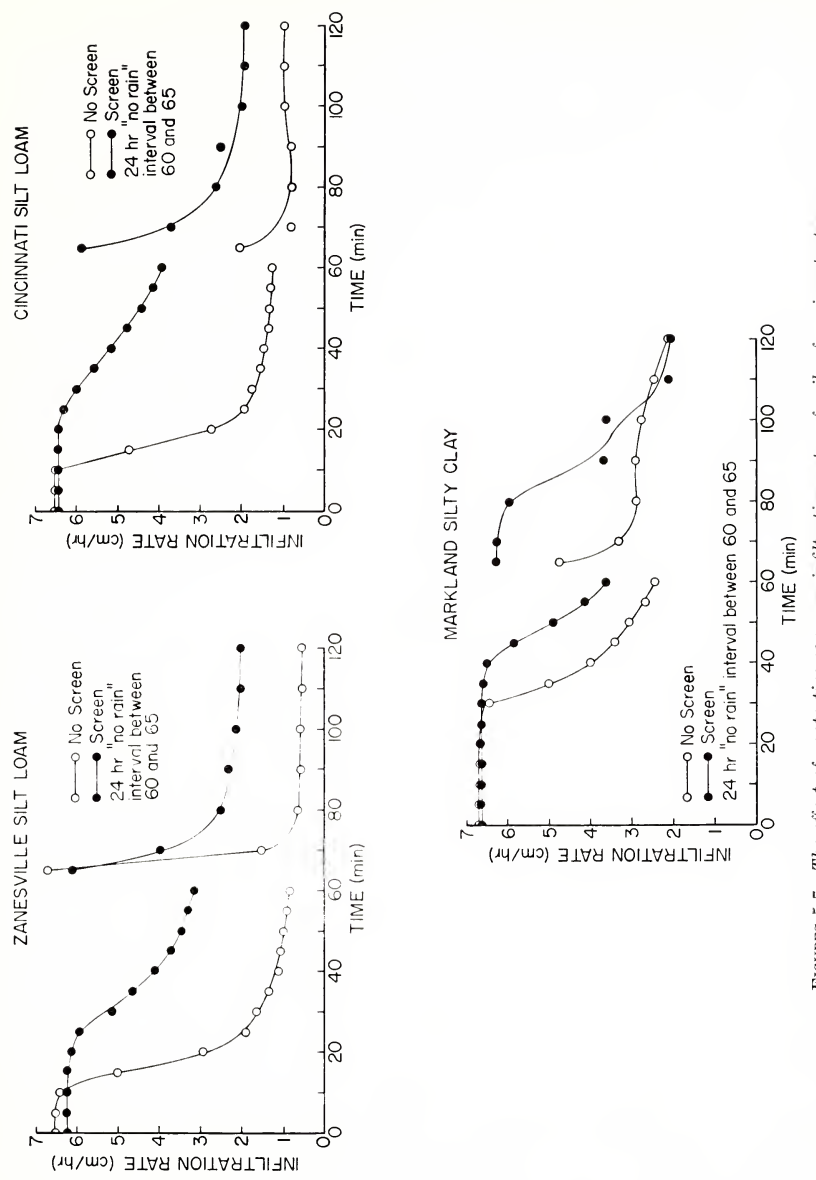
After only 10 minutes of rain, a seal had formed on the Fox silt loam soil and little further reduction in infiltration rate occurred after 30 minutes of rain during the first 1-hour storm (Fig. 4). Infiltration rates on the bare plots were 35% and 80%, respectively, of those on the protected plots after 1 and 2 hours. The swelling of the clay present is thought to be responsible for the rapid decrease in infiltration on the protected plot during the second-day test.

Figures 5 and 6 illustrate the influence of rainfall energy on the infiltration rates of soil high in silt. When not protected these two soils, Zanesville and Cincinnati, containing 72% silt, both exhibited a marked reduction in infiltration after only 15 minutes of rain. Further reductions in infiltration rate after 30 minutes of rain were relatively small. Infiltration rates on the bare plots after the first hour of rain were approximately 35% of those on protected plots for both soils. After 2 hours, the differences between rates on the bare and protected plots were greater on the Zanesville (61%) than on the Cincinnati (34%). The reduced infiltration with time on protected plots indicate that either internal soil properties are controlling infiltration rate or that the rain falling through the screenwire contained sufficient energy to produce seals on these particular soils.

Rainfall energy did not result in a major reduction in infiltration on the Markland silty clay (Fig. 7). After 60 minutes of rain, the rate on the bare plot was still 60% of that on the protected plot and there was essentially no difference between treatments at the end of 2 hours. The high level of water stable aggregation resulting from high clay content and relatively high organic matter levels prevented the formation of a severe surface seal on this soil.

These results show that when exposed to high energy rainfall, all of the soils tested are subject to surface sealing, thus reduced water infiltration. The magnitudes of these differences vary greatly among soils and are to a great extent controlled by soil texture and structure. The soils most seriously affected are the medium textured soils where infiltration rates into exposed soils can drop to as low as ⅕ those of protected soils after only a few minutes of rain. Organic matter and clay contents when sufficiently high to produce stable structure greatly reduce the soil sealing effect of rainfall energy.

The realization that the rate of water infiltration into soils can be reduced as much as four or five-fold because of surface sealing, is essential in many forms of hydrological planning.



FIGURES 5-7. *The effect of protective cover on infiltration rates of soils of various textures.*

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