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Rain infiltration into loess soil under different rain intensities and slope angles

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Abstract

The impact of rain intensity on loess soil infiltration rate was investigate. The experimental work was done under laboratory condition at State Key Laboratory of Soil Erosion and Dry land Farming on the Loess Plateau, Shanxi Province, China during 2006-2009. The soil was subjected to three rain intensities (30, 60 and 90 mm h^{-1}), for two hours duration under three different slope angles (5˚, 15˚ and 25˚). Samples of a silty loam-loess soil were taken and analyzed using standard analytical methods. The experiments were performed using a drip-type rainfall simulator fixed at 16 m above the ground. The rainfall over perforated metal boxes of 60 cm x100 cm x10 cm which covered with 7.5 cm layers of the soil material, uniformly distributed over a 2.5 cm layer of coarse sand. Infiltration was described by nonlinear relationship. The rain intensity showed notable effect on infiltration rate. Whereas infiltration rate tend to decrease with increase in rain intensity, it falls from the initial rate of 36.3, 48.8 and 78.8 mm h^{-1} , to final rate of 30, 25.2 and 20 mm h1for 30, 60 and 90 mm h^{-1} rain intensities, respectively. On the other hand, the infiltration rate remains unchanged with changing in slope angle. The study concluded that increasing in rain intensity decreasing infiltration and increasing loess soils losses.

Keywords: *rain infiltration, loess soil, rain intensity, slope angle.*

1. Introduction

Loess soils are among the most erodible soils. Therefore, evaluating and enhancing infiltration is paramount in controlling soil loss (Römkens et al.1985). Infiltration is the process of water penetrating into soil, generally referred to as the downward movement of water from the soil surface (Bouwer, 1986). The permeability of a soil under rainfall is of great importance in such studies as hydrological processes (Brooks, 1997), irrigation management, soil erosion (Jiang, 1997), movements of water and solutes in soils. Permeability is closely related to the texture, structure, slope and moisture content in soil profile. It conceptually decreases with time (Scott, 2000) and eventually approaches a steady value, called steady or final infiltration rate. Rain infiltration is determined by a number of factors include rainfall characteristics, soil hydraulic properties, soil condition, and topographic factors (Römkens et al.1985).

Infiltration rates have been observed to increase, decrease or remain unchanged with changing slope angle (Fox at al. 1997). Slope angle influences several critical factors affecting the infiltration process; these include surface storage, effective rainfall intensity and overland flow depth. Bradford and Huang (1992) found that infiltration rate increased with increasing slope angle for soil most susceptible to surface sealing. Bryan and Poesen (1989) observed that infiltration increases with slope angle only where rill development is associated with increasing slope angle.

Decreasing infiltration rate with increasing slope angle has commonly been observed in the field in different types of soils (Sharma et al.1983). Increasing in slope angle in specific surface roughness lead to decrease surface storage capacity, ponding pressure head and infiltration rate (Fox at al. 1997).

Luk et al.(1993) used simulated rainfall to examine the influence of slope angle on infiltration in a loess soil and found that the increasing and decreasing in infiltration rate with increasing slope angle depend mainly on storm duration. Despite numerous studies, the relationship between slope angle and infiltration rate remains unclear (Fox at al. 1997).

Eroded soil particles, which resultant from a high flow rate can cause blocking of soil pores, or cause surface sealing, and reduce soil permeability (Helalia, et al.1988 and Morin, et al.1996). High rainfall intensity and run-on flow rate cause faster wetting rate of surface soil, which may cause much more severe soil aggregates breaking down than low

rainfall intensity and run-on flow rate, which result in blocking of soil pores, reduced permeability and final infiltration rate.
The objective of this work was to study the effect of different rainfall intensities of two hours duration (30, 60, and 90 mm h1-) on infiltration rate of a loess soil under different slope angles (5˚, 15˚ and 25˚).

2. MATERIALS AND METHODS

2.1 Materials

The infiltration measurements were conducted under simulated rainfall using a drip-type rainfall simulator. The drippers were fixed at 16 m above the ground, about 14 m from the soil surface. It rain over an area 4x9 m, which the final velocity of the raindrops approaches 98% of that of natural rain. Rain intensities (30, 60 and 90 mm h-1) were maintained using a peristaltic pump. The water used for the simulated rainwater was characterized by EC (0.87 dS m-1) and SAR (1.94). The boxes of 60cm x100 cm x10 cm for each one were placed under the rain simulator on a supporting framework, containing the selected soil, (plate 1).
The soil used was a silty loam-loess (Calcic Cambisol, it was taken at (0-300 mm) depth, from Ansai, Shanxi province, china, and was analyzed using standard analytical methods as described by Page et al., (1982) and Klute, (1986). The selected soil physical and chemical properties are given in Table 1.

2.2 Methods

The soil samples were air-dried and crushed by hand to pass through a 5 mm sieve. Layers of the soil material, 7.5 cm deep, were uniformly packed into perforated metal boxes, over a 2.5-cm layer of coarse sand. The bulk density of the soil in the boxes was maintained at 1.15 (±0.02) g cm-3.
During each storm, runoff water and eroded sediments were collected continuously, at the same duration, using graduated cylinders placed underneath a special outlet at the bottom of each box. After recording the Runoff volume, the sample was dried at 105 0C, using oven to determine the mass of the eroded sediment. The method was replicated three times under the same conditions for each treatment.
Three rainfall intensities (30, 60, and 90 mm h-1) were selected to study the effects on the infiltration rate under three different slope angles 5o, 15o, and 25o.

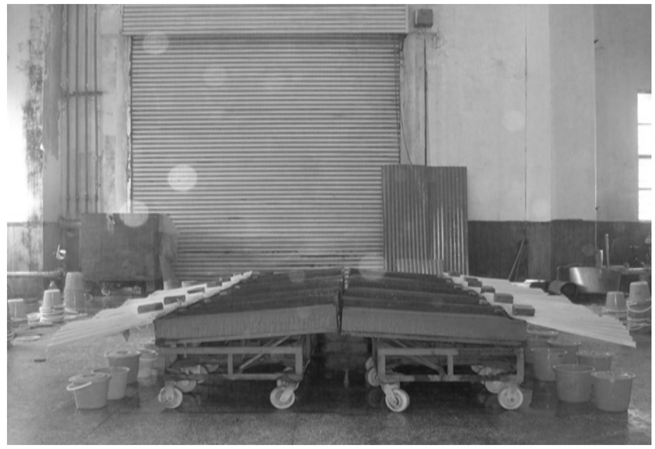


Plate 1 Perforated Boxes

Table 1: The loess soil properties

Soil Type	Particle-size distribution			CEC mmol kg^{-1}	ESP %	Organic matter %
	Sand %	silt %	clay %			
loess	22.4	65.1	12.5	42.2	2.5	0.19

CEC = Cation Exchange Capacity.

ESP = Exchangeable Sodium Percentage

Infiltration data obtained from the rainfall simulator were analyzed with nonlinear equation proposed by Morin and Benyamini (1977):

$$I_t = (I_i - I_f)e^{-ypt} + I_f \quad (1)$$

Where: I_t = instantaneous infiltration rate (mm h-1)
I_i = initial infiltration rate (mm h-1)
I_f = final infiltration rate (mm h-1)
y = soil coefficient related to surface aggregate stability
p = rain intensity (mm h-1)
t = time (h) from the beginning of the storm

Then the measured I_t, I_f, and p values regressed to a nonlinear to calculate the other two parameters of the equation (Ii and y) that gave the best coefficient of determination (R2 > 0.9) between the paired calculated and the measured It values.

3. RESULTS AND DISCUSSION

3.1 The effects of rainfall intensities on infiltration rate (IR):

The effect of rainfall intensities (30, 60, and 90mm h-1) on infiltration rate (IR) is depicted in Figure1. The general observed trend was that infiltration rate initially increased and then decreased as the rainfall intensity rose. Whereas, the infiltration rate (IR) of the targeted soil fall from the initial rate of 36.3, 48.8 and 78.8 mm h1- , for 30, 60 and 90 mm h1- rain intensities, to final infiltration rate (IR) of 30, 25.2 and 20 mm h1-, respectively. High rainfall intensity and run-on flow rate cause faster wetting rate of surface soil, which may cause much more severe soil aggregates breaking down than low rainfall intensity and run-on flow rate, which result in blocking of soil pores, reduced permeability and final infiltration rate. High rainfall intensity and impact of raindrops, combined with a low concentration of electrolytes in the water caused the IR to fall. A similar observation was made by Ben-Hur et al.(1997), who found that soils with moderate (10-20%) clay percentage and low content of organic matter(OM) are most susceptible to crusting. Also the current result is supported by the finding of Helalia, et al.(1988) and Morin, et al.(1996).

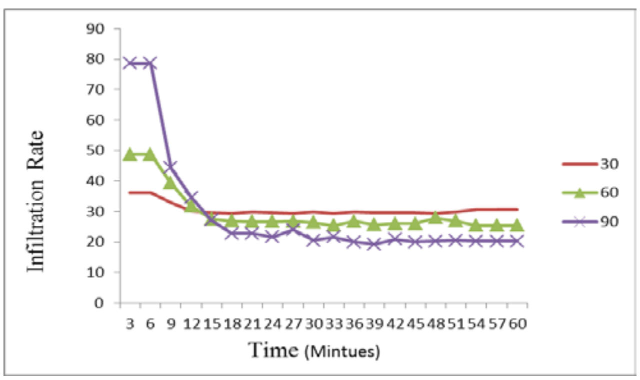


Fig.1: Effect of rainfall intensities (30, 60, 90 mm/h) on infiltration rate (mm/h)

As presented in figure 2 the slope angles were effect like on infiltration rate, which the infiltration remain unchanged with change in slope angle. This result agreed with the finding of Fox et al.(1997), who stated that infiltration rate have been observed to increase, decrease, or remain unchanged with changing slope angle. Also reported that despite numerous studies, the relationship between slope angle and infiltration rate remain unclear. The current result was contradictory with the findings of Bradford and Huang (1992) infiltration rate increased with increasing slope angle, and Sharma et al.(1983) infiltration rate decreased with increasing slope angle.

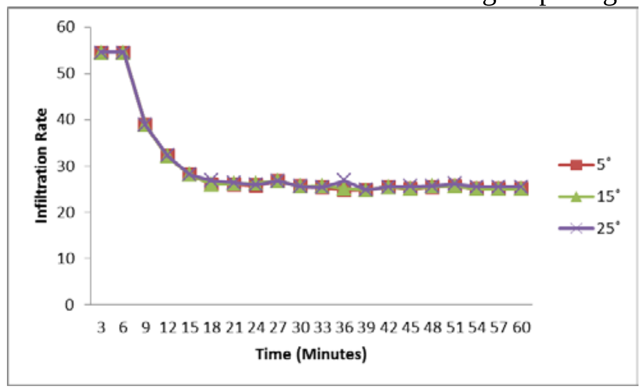
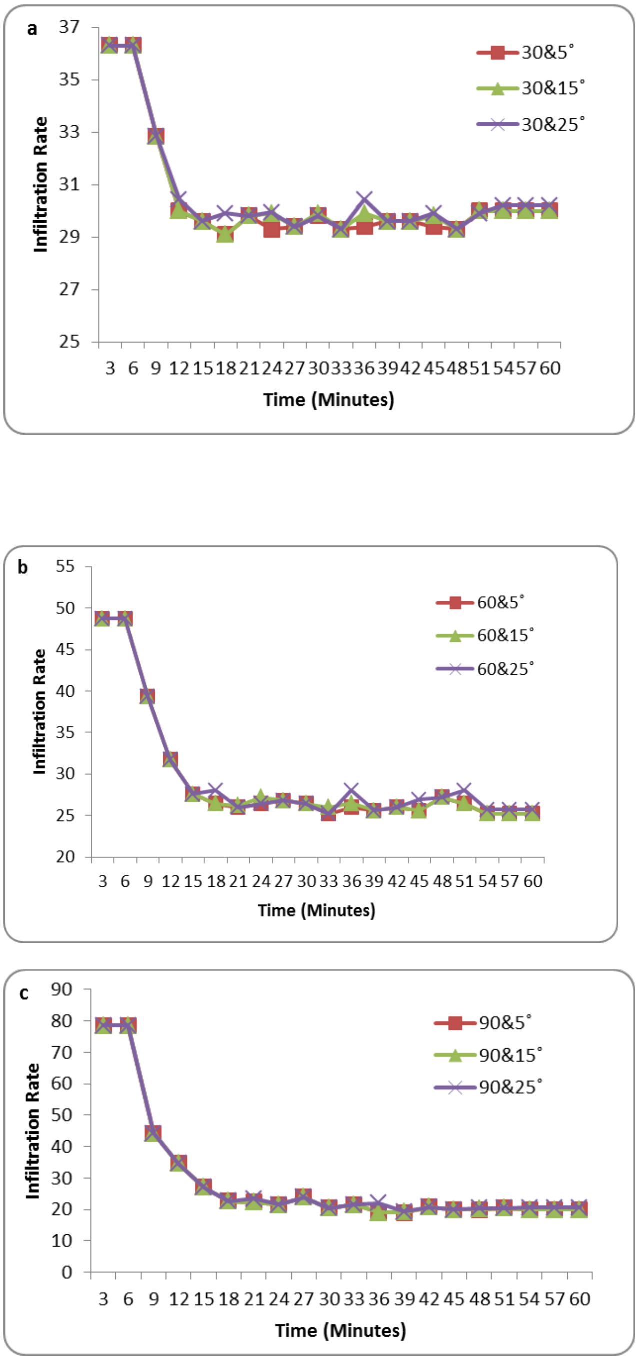


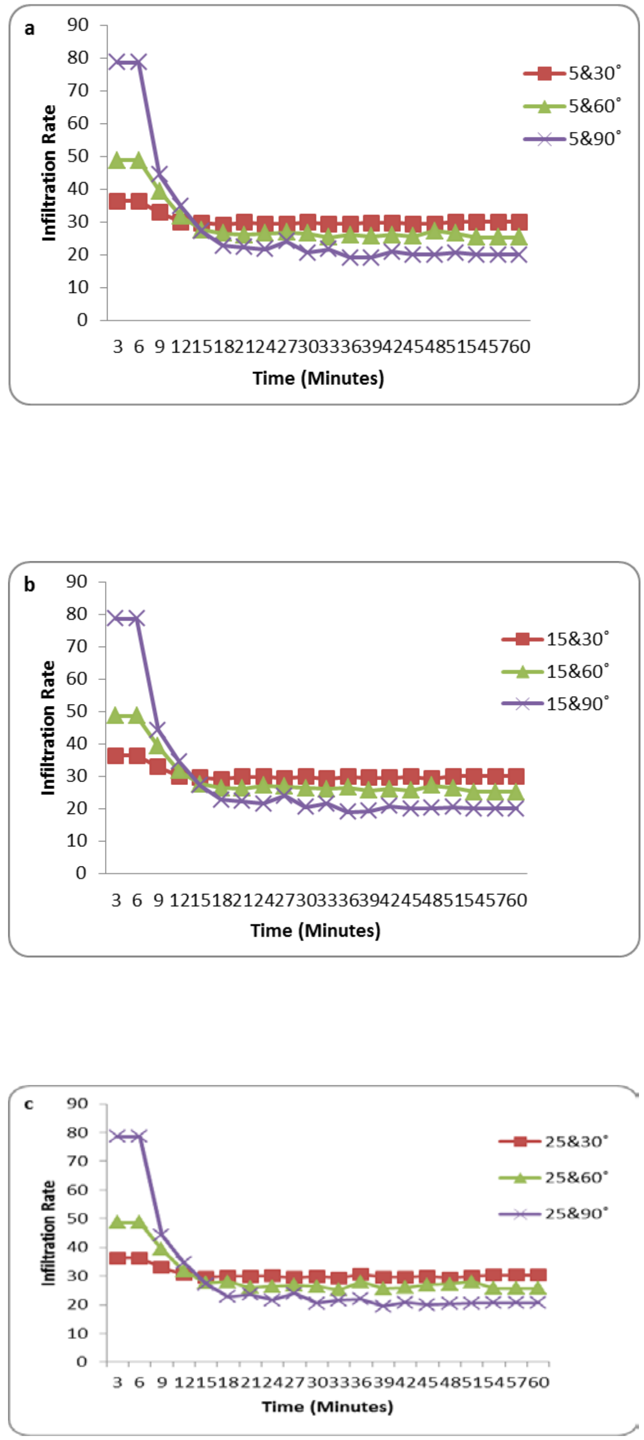
Fig. 2: Effect of slope angles (5˚, 15˚ and 25˚) on infiltration rate mm/h

3.2 Effect of Slope angle and rain intensity on infiltration rate:

As illustrated in figures3 (a, b, c) the effect of slope angle with rain intensity on infiltration rate reflect bit different, whereas the effect of slope angles seem to be more concurrent with increasing in rain intensity. The slope angle (25˚) with 30 and 60 mm/h rain intensities showed bit increasing in infiltration rate than slope angles (5˚ and 15˚), while the three slope angles with the rain intensity 90 mm/h gave typical identical curve; this trend was consistent with the finding of Luk et al.(1993). On the other hand, the rain intensities (30, 60, 90 mm/h) gave the same effect on infiltration rate with slope angles (5˚, 15˚ and 25˚), whereas the identical curves were obtained (figures4 (a, b, c)). This result confirmed that the relationship between infiltration rate and slope angles remain unclear and need more studies as stated by Fox et al.(1997)..



Figs 3(a,b,c): Effect of rainfall intensities (30, 60, 90 mm/h) under different slope angles on infiltration rate (mm/h)



Figs 4(a, b, c): Effect of slope angles (5˚, 15˚, 25˚) under different rainfall intensities on infiltration rate (mm/h)

4.Conclusions

The conclusion that can be drawn from this study, is that infiltration rate tends to decrease with increasing in rain intensities, which lead to increase loess soils losses. The slope angles (5˚, 15˚, 25˚) showed the same effect on infiltration rate, and infiltration remain unchanged with changing in slope angles. Further studies to estimate the effect of slope angles and rain intensities on infiltration rate are highly recommended.

5. References

[1] M. Ben-Hur and R., Karen, "Polymer effects on water infiltration and soil aggregation. Soil". Sci. Soc.Am. J. vol 61, (1997) pp 565-570.

[2] H., Bouwer, Intake rate: Cylinder infiltrometer. Pp 825-843 in Klute A., Methods of Soil Analysis, part 1: Physical and Mineralogical Methods, 2nd Ed. Madison: American Society of Agronomy and soil science society of America. 1188p. ISBN 0-89118-088-5. (1986).

[3] J.M., Bradford, and C., Huang, Mechanisms of crust formation: physical components. In: Sumner, M. E., Stewart, B. (Eds.), Soil Crusting Chemical and Physical Processes. Advance in soil science Lewis Publisher, Florida. (1992).

[4] K. N., Brooks, P. F., Folliott, and H. M., Gregersen, Hydrology and the Management of Watersheds, Iowa: Iowa State University Press, 69-78: (1997).

[5] R.B., Bryan, and J., Poesen, "Laboratory experiments on the influence of slope length on overland flow, percolation, and rill development". Earth Surf. Process. Landforms Vol 14, (1989), pp. 211-231.

[6] D.M., Fox, R.B., Bryan, and A.G., Price, "The influence of slope angle on final infiltration rate for inter-rill conditions". Geoderma vol 80, (1997), pp. 181 – 194.

[7] A. M., Helalia, G. J., Letey, and R. C., Graham, Crust formation and clay migration effects on infiltration rate, Soil Science Society of America Journal, vol 52, (1988), pp. 251-255.

[8] D. S., Jiang, Soil Erosion and Control Models in the Loess Plateau, Beijing: China Water and Electricity Press, pp. 27-99. (1997).

[9] A., Klute, Methods of Soil Analysis. Part 1. Physical and mineralogical methods. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI. (1986).

[10] S.H., Luk, Q., Cai, and G.P., Wang, "Effects of surface crusting and slope gradient on soil and water losses in the hilly loess region, North China". Catena Suppl. Vol (1993), pp.24, 29-45.

[11] J., Morin, and Y., Benyamini, "Rainfall infiltration into bare soils. Water Resource". Res. Vol 13, (1977), pp. 813-817.

[12] J., Morin, and J., Van Winkel, "The effect of raindrop impact and sheet erosion on infiltration rate and crust formation" Soil Sci. Soc. Am.J., vol. 60, (1996), pp. 1223-1227.

[13] A. L., Page, R. H. Miller, and D. R. Keerney Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI. (1982).

[14] M., Römkens, Baumhardt, R., Parlange, J., Whistler, F., Parlange, M., and S., Prasad, "Rain-induced surface seals: their effect on ponding and infiltration". Annuals, Geophysics vol 4, (1985), pp.417–424

[15] H. D., Scott, Soil Physics, Iowa: Iowa State University Press , 246-280. (2000).

[16] K., Sharma, H., Singh, and O., Pareek, "Rainwater infiltration into a bare loamy sand". Hydrological Science Journal vol. 28, (1983), pp.417-424.

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