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Original Research Paper

Effect of Vegetation Cover Types on Soil Infiltration Under Simulating Rainfall

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ABSTRACT

In this study, simulated rainfall was applied to study the process of runoff generation and water infiltration under the cover of herbaceous vegetation at the preliminary succession stages. Results indicated that at the preliminary succession stages, as soil texture was loose, water infiltration was high. With the vegetation succession and the accumulation of organic matter in the soil, both physical and chemical properties of the soil were improved, which made the soil texture tight, and water infiltration rates decrease. With the progress of the rainfall, parts of the microbiotic soil crust were destroyed by raindrop impact, and water infiltration rates were improved. This result indicated that the existence of microbiotic soil crust reduced the soil infiltration rate. Thus, it is of great importance to improve soil infiltration by destroying the microbiotic soil crust with proper measures such as grazing in arid and semi-arid areas.

INTRODUCTION

It's well known that soil hydrologic condition is the result of complex interactions of soil and vegetation factors. Infiltration rate and sediment production integrate these factors and are good indicators of hydrologic condition (Thurow 1986). Vegetation succession is the result of interactions between soil and vegetation, which induced changes in both soil and vegetation. One consequence of this change in relative composition of vegetative cover is the amelioration of soil (Fisher 1990) resulting in an alteration of the hydrologic characteristics of the site (Thurow 1991). Under the cover of the vegetation, the accumulation of organic matter under trees and the moderation of soil microclimate (Kittredge 1948) favour earthworm and microbial activity, and the creation of water stable soil aggregates (La 1987). The cover provided by the canopy and litter intercept precipitation, thereby dissipating the kinetic energy of falling rain that could break the aggregate bonds. The enhanced soil structure that results from these factors improves infiltration. Consequently, infiltration rates are often observed to be highest under trees and shrubs, followed in decreasing order by bunchgrasses and sodgrasses (Box 1961, Blackbum 1975, Wood & Blackbum 1981, Knight 1984, Thurow 1986).

Currently, the amount of ground cover required to control erosion has been the topic of intense debate. A number of studies in the semi-arid woodlands of eastern Australia have demonstrated the effect of increasing cover of ground-storey plants, particularly grasses, on reducing runoff and erosion (Pressland & Lehane 1982, Eldridge & Loen 1993). Ground cover includes a wide variety of soil surface cover features including both living and dead ground-storey vegetation, biological or cryptogamic soil crusts (moss, lichens, liverworts, algae and fungi), litter, dung and stones. In a general sense, factors such as soil physical and chemical properties, rainfall intensity and slope are important determinants of erosion on red earth soils (Eldridge & Loen 1993). However, ground cover is generally regarded as critical (Thurow 1991) although the impact of different forms of ground cover on infiltration and erosion varies considerably. Perennial plants are generally more effective than annual or ephemeral plants (Eldridge & Rothon 1992). Cryptogamic crusts are highly effective at preventing erosion (Eldridge 2001b), but their role in soil water flow is generally moderated by the soil physical status (Eldridge et al. 1995).

In addition, human- or nature-induced disturbance also has profound effect on soil infiltration and erosion through its impact on soil and vegetation. Researches has verified that burning reduced infiltration rates in soils of Missouri Ozark forests (Arend 194 l), of chaparral communities of northern California (Sampson 1944), of Flint Hills tall grass prairie of Kansas (Hanks & Anderson 1957), and of Douglas fir *(Pseudotsugu menziesii)* forests of British Columbia (Beaton 1959). However, Scott (1956) reported increased infiltration on upland soils in California following fire, as did Tarrant (1956) for a ponderosa pine (***Pinus ponderosu***) forest in eastern Washington. Veihmeyer & Justin (1997) on oak site, and Justin et al. (1997) also detected no significant difference between cut and burned juniper sites. Darrell et al. (1978) have verified that the fire affected soil infiltration and sediment production, but its effect varied with soil moisture content. Seasonal variability in precipitation may interact with grazing to alter the hydrologic condition of rangeland (Warren et al. 1986).

Currently in China, ecological restoration in West China was one of the main missions for eco-environment construction. Little studies were focused on the soil hydrological changes with the recovery of the vegetation. In this research, simulating rainfall was applied to study the effect of vegetation cover types on runoff and soil infiltration. This study was conducted to study and compare the quantity and components of vegetation cover, as determined by point frames, at different succession stages; and to determine the relative merits of soil surface cover components of live plants, litter, surface vegetation, microbiotic soil crust and their combination on runoff production.

MATERIALS AND METHODS

Site conditions: The studies were conducted during the growing season of 2002 on simulating rainfall plots with its projection area of 1 × 4m^2. Experimental sites were located in Wangdong Watershed of ISWC (Institute of Soil and Water Conservation) Changwu Field Experimental Station of CAS (Chinese Academy of Sciences). Local elevation was ranged from 950-1225m. Its climate belonged to warm temperate continental seasonal climate, with its average annual temperature 9.1°C, average annual rainfall 584.1mm, most of which was concentrated in July-September. Main soil types on most sites were loess.

Since the foundation of the station in 1986, effective measures were carried out to protect and restore local environments. Currently, vegetation on most slopes was covered with perennial herbaceous grass of *Stipa bungeana* and *Bothriochlon ischaemum*, and the associate species mainly included *Lespedeza bicolor*, *Dendranthema indicum*, etc. Considering this, simulating rainfall was applied on natural annual and perennial herbaceous grass plots (Table 1).

Simulating rainfall plots: To annual herbaceous plots, 4 plots with different vegetative cover were determined as simulating rainfall plots with 3 target-rainfall intensity of 1mm/min, 2mm/min, and 3mm/min from the height of 2m (upper)~4.64m (bottom), which was applied in the sequence of 2mm/min, 1mm/min and 3mm/min, 24 hours followed another one.

While to perennial herbaceous plots, before the application of rainfall, vegetation conditions on the slope were investigated, and the results indicated that the distribution of vegetation on the slope was even. Thus, the whole slope can be considered as identical for simulating rainfall. To verify the effect of different vegetative components on runoff production, simulating rainfall plots were setup with different treatments. In one plot, upper parts of the vegetation was clipped to a 2cm stubble height; while in another one, herbicide was spread over all vegetation, then fire was applied to get rid of all the surface cover (including litter, live vegetation). After that, simulating rainfall of different rainfall intensity (1mm/min, 2mm/min, and 3mm/min) was applied to each plot at the same height and sequence to that on the annual plots.

Local main soil type was loess, with its soil clay content (<0.01mm) 25%, >0.25mm water stable aggregate content 8.12%, and organic content 0.746%.

Rainfall simulating and runoff study: In this study, a new rainfall simulator was designed, which was consisted by 16 pieces of boards, whose size was 26 × 102.0cm^2, with 333 6.5# medical syringe needles on it. Water-supplying system was designed at certain height to supply stable pressure. Rainfall intensity was controlled by monitoring the water discharge into the simulator, which indirectly influenced the air pressure in the simulator.

Raindrop diameter distribution characters of this kind simulator (Table 2) indicated that there was no significant difference of raindrop size under different rainfall intensity. Soil moisture content on the profile within 50cm was determined by soil auger before the rainfall. Runoff production of each minute was determined by measuring its volume. At the same time, runoff gathering speed was determined by dying method on 5 sections from the lower part to the upper part of the simulating rainfall plots.

After that, infiltration curve was calculated according to the equation proposed by Horton:

$$f = f_0 + (f_c - f)e^{-kt}$$

Where f-infiltration ability, f_0-preliminary infiltration ability, f_c-stable infiltration rate and t-infiltration time.

Vegetative cover and biomass: Based on former studies, vegetative cover and ground cover was estimated by point-frame method. The point-frame method provided statistically reliable quantitative estimates of vegetation and cover on grazing land at several intensities in former studies (Hoffmann et al. 1983, Hoffmann & Ries 1991). Various cover components can be estimated from either the first point contact by the needles of the point frame, or from contact at the soil surface. In this study, vegetative cover measurements

Table 1: General conditions of simulating rainfall plots.

No of plots	Vegetation types	Gradient	Vegetation cover	Soil bulky density	Slope exposition	Location on slope
1	Annual	32	0.69	1.1	Southern	Under
2	Annual	32	0.42	1.08	Southern	Under
3	Annual	32	0.78	1.06	Southern	Under
4	Annual	32	0.88	1.05	Southern	Under
5	Perennial	20	0.81	1.23	Southern	Middle
6	Perennial (clipped)	20	0.82	1.22	Southern	Middle
7	Perennial (fired)	20	0.80	1.25	Southern	Middle

Table 2: Raindrop diameter distribution under different rain intensity.

Rainfall intensity	1.483mm/min	1.75mm/min	1.8mm/min	1.99mm/min	2.35mm/min	2.4mm/min
Raindrop diameter	0.30	0.27	0.33	0.30	0.36	0.31

Table 3: Vegetation production of the upper parts (g/m^2).

	1	2	3	4	5	6	7
Biomass	725.972	606.366	555.844	506.772	840.588	846.776	842.784
Cover	0.83	0.72	0.63	0.43	0.81	0.82	0.8

Note: In the Table, plots 1, 2, 3 and 4 were located on the annual herbaceous grass, while plots 5, 6 and 7 on perennial herbaceous vegetation.

Table 4: Surface cover composition on the rainfall simulating plots.

	Micobio-crust	Live vegetation	Surface vegetation	Litter	Bare soil
Plot 1	0.01	0.30		0.12	0.57
Plot 2	0.00	0.44		0.24	0.32
Plot 3	0.02	0.40		0.45	0.13
Plot 4	0.03	0.36		0.52	0.09
Perennial plot	0.10	0.53	0.06	0.24	0.07
Clipped plot	0.14	0.23	0.09	0.34	0.20
Fired plot	0.16	0.05	0.13	0.18	0.48

Table 5: Runoff gathering speed on the simulating plots (m/s).

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7
Section 1	0.113	0.131	0.094	0.091	0.071	0.076	0.089
Section 2	0.085	0.100	0.070	0.085	0.040	0.042	0.060
Section 3	0.069	0.070	0.068	0.070	0.032	0.038	0.051
Section 4	0.063	0.075	0.051	0.055	-	-	0.034
Section 5	0.025	0.036	0.015	0.032	-	-	-

Table 6: Changes of soil surface cover types before and after the rainfall on plots.

	Microbio-crust	Live vegetation	Surface vegetation	Litter	Bare soil
Before first rainfall	0.24	0.30	0.08	0.19	0.19
Before second rainfall	0.16	0.23	0.12	0.28	0.20
Before third rainfal	0.10	0.19	0.15	0.34	0.22

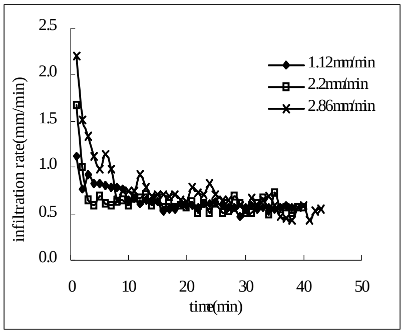

Fig. 1: Plot 4 (C = 0.88).

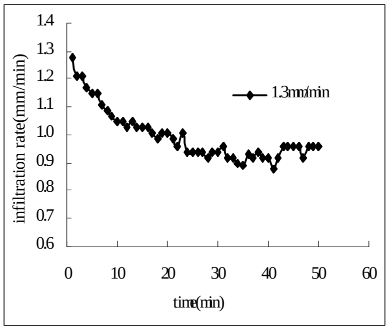

Fig. 2: Plot 3 (C = 0.78).

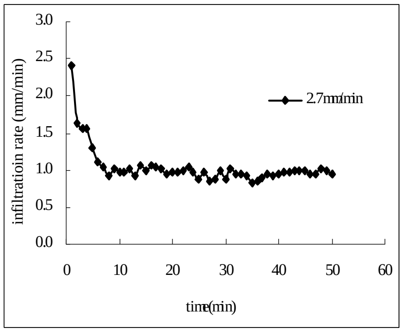

Fig. 3: Plot 2 (C = 0.42).

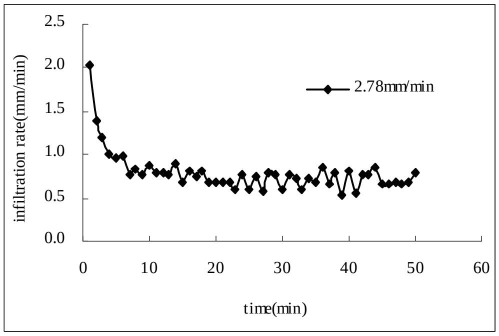

Fig. 4: Plot 1 (C = 0.69).

were taken within runoff plots with vertical point frames of 33 sliding pins spaced about 3.3cm apart. Plots cover estimates were taken with 10 frames of 33 pins producing 330 hits before the simulating rainfall. Vegetation production was determined by hand clipping, oven drying at 105°C, weighing live plants and litter from eight 0.25m^2 plots within simulating rainfall plots after the application of the rainfall.

RESULTS

Upper part biomass and cover types composition of annual and perennial vegetation: According to former studies, high moisture and high temperature are particularly favourable for the activity of microorganisms of the soil and hence favour a rapid rate of decay (Melvin et al. 1995, Liacos 1962a, 1962b). Under the cover of the annual vegetation, soil moisture evaporated quickly, most part of the vegetation litter was mineralized, and little organic matter was returned to soil. While under the cover of perennial vegetation, microenvironment favoured the activity of the microorganisms in soil, and vegetation litters decomposed easily and formed humus, which consequently improved soil both physical and chemical properties. Judging from Table 3, it was clear that, on the annual vegetation plots, with the increase of vegetation cover, the aboveground biomass of vegetation increased (Table 3), which suggested the increase of amount of organic matter returning to soil. While on the perennial vegetation plots, upper part biomass of vegetation was close with the similar vegetation cover, and was greater than that on the annual plots with similar vegetation cover.

Former studies (Vitt 1989) have verified that the formation of microbiotic soil crust and surface vegetation (moss, lichen, algae, fungi) was closely related to its microenvironments, and can be treated as a kind of indictor species of the micro-environment. From the Table 4, there was almost no microbiotic soil crust and surface vegetation on annual herbaceous vegetation plots, while on the perennial herbaceous vegetation plots, there were all cover types, including live vegetation, surface vegetation (moss and lichen), litter and microbiotic crust, even on southern exposition slope. On the clipped plots, as its canopy was removed handily, its live vegetation cover decreased, other cover types (surface vegetation, litter, microbiotic crust) under it were exposed and their cover increased. On the fired plots, although fire has destroyed most parts of the vegetation, due to the drying time and fire intense, there were still live vegetation and litters left on the soil surface. As most surface cover was removed by fire, more surface vegetation was exposed. This result indicated that microenvironments under the cover of perennial herbaceous grass have been greatly improved. Surface cover composition on perennial vegetation plots was more complex than that on the annual vegetation, which indicates that the perennial herbaceous grass may play more important ecological role (such as soil and water conservation) in the nature.

Soil infiltration on annual vegetation plots: Soil infiltration rates in plots 1-4 with respect to time are given in Figs. 1-4. Annual vegetation plots were located under the bottom of gully. There were some litters covered on soil surface, but almost no microbiotic soil crust and surface vegetation (moss, lichen or fungi). As the stable infiltration on the same site was similar, not all the infiltration process was listed in order to make the figure more clearly.

According to the interactions between soil and vegetation in ecological succession, annual species usually grow

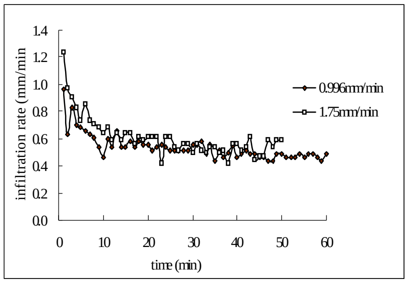

Fig. 5: Natural grasses plot.

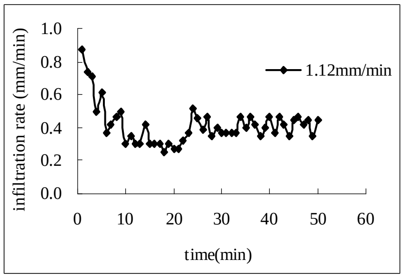

Fig. 6: Vegetation clipped plot.

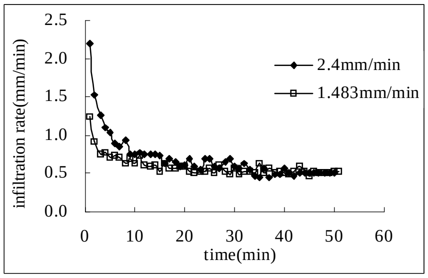

Fig. 7: Fired plot.

on the soil where soil texture was loose, and aeration conditions were better. Simulating rainfall results on plot 1~4 showed that the soil infiltration tended to be stable in 15 minutes. And the stable infiltration rates on plot 1~4 were higher at 0.71, 0.94, 0.92 and 0.55mm/min respectively. With the increase of vegetation cover, soil infiltration decreased.

Judging from the runoff gathering speed on the plots (Table 5), it was clear that with the increase of ground cover, runoff gathering speed was lowered, which indicated that the existence of the vegetation helped to lower the runoff speed, and consequently the runoff erosivity. Also, runoff speed tended to the increase when more runoff gathering together.

Soil infiltration of perennial vegetation plots: With the development of vegetation succession and the accumulation of organic matter in the soil, together with the soil falling under the effect of gravity and rainfall water, soil texture tended to be tight, and the aeration conditions were lowered. The changed soil had important effect on soil hydrological properties. Simulating results (Fig. 5) indicated that stable infiltration rate on perennial vegetation plots was lower, and its stable infiltration rate was under 0.47mm/min. Runoff gathering speed (Table 5) was lowered on perennial plots too, and consequently runoff erosivity.

Simulating results on clipped plots (Fig. 6) indicated that at the start of rainfall (0-20min), stable soil infiltration rate was 0.38mm/min. With the progress of rainfall (24-50min), soil infiltration increased to 0.52mm/min. Investigations of soil surface cover types before and after the rainfall (Table 6) showed that the cover of microbiotic soil crust decreased. These results indicated that this crust was broken down gradually under the splash of the raindrop after clipping off the canopy of perennial vegetation cover. The increase of litter cover was a result of increased exposure of buried residues by surface flow. It was clear that the existence of microbiotic soil crust lowered soil infiltration rate. Removing its protection by clipping the canopy over it can destroy this crust, and improve the soil infiltration rate. Soil infiltration on the burned plot (Fig. 7) was close to that on the clipped plot in later time. The main reason was that fire has destroyed almost all the upper pats (litter and upper parts of live vegetation) of the vegetation. Most of the crust was exposed under the direct splash of raindrop, and was destroyed quickly. Thus, soil infiltration rate was close to that on clipped vegetation plot in later time of 20~50min. With less impoundment of the litters and vegetation, runoff gathering speed on the burned plot was a little higher than those on the natural grassland and clopped plot. But due to the existence of surface vegetation (moss and lichen) and litters, runoff velocity was lowered compared to that on the annual plots (Table 5), which indicated that the runoff erosivity on the perennial vegetation plots was decreased.

DISCUSSION AND CONCLUSIONS

Compared to the soil infiltration processes and runoff gathering speed on the annual and perennial vegetation plots, following conclusions can be drawn:

On the annual vegetation plots, soil infiltration rate was higher as the aeration conditions were better. With the increase of vegetation cover, soil infiltration was lowered, together with the runoff gathering speed.

With the succession development, both soil physical and chemical conditions were improved greatly, and soil texture tended to be tighter, which resulted in the decrease of soil infiltration rate. The existence of surface vegetation protected the soil from direct splash of raindrop, and was of great importance in soil conservation. Microbiotic soil crust decreased soil infiltration rates, and was unfavourable for water conservation.

Thus, proper human activities (including mowing, grazing, fire, etc.) in arid and semiarid areas would help to destroy the microbiotic soil crust over soil surface, and to improve soil infiltration ability, but increase the risk of soil erosion.

Based on the results from this study, rational proposals can be proposed for local ecological construction. Currently, forbidding grazing has been carried out for vegetation rehabilitation in parts of West China. Considering the hydrological properties of grassland under different human disturbances, reasonable human activities (grazing, fire, etc.) will help to destroy the compact microbiotic crust, and improve soil infiltration. Of course, such disturbance increased the risk of soil erosion, and precision plan should be made for the balance between soil infiltration and erosion.

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