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Compacted microcatchments with local earth materials for rainwater harvesting in the semiarid region of China

Xiao-Yan Li*, Jia-Dong Gong

Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, 260 Donggang West Road, Lanzhou 730000, People's Republic of China

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Abstract

Low cost microcatchment treatments for rainwater harvesting are needed under the local poor economic conditions in the semiarid loess regions of northwest China. This paper was intended to study the effectiveness of runoff yield from compacted catchments with some local earth materials under the natural rainfall. The compacted catchments were constructed with uniformly mixed loess, laterite and fine sand at the ratio of 1:1:1. The results showed that rainfall–runoff efficiency from such compacted plots was 33% of the total rainfall as compared to 8.7% from the untreated plots. The compacted catchments had low infiltration rate, and the minimum precipitation required to produce runoff (threshold rainfall) was 4 mm under no antecedent rainfall effects and 1.9 mm under antecedent rainfall effects. In contrast, the threshold rainfall was about 8.5 mm for the untreated catchments under no antecedent rainfall effects and 6 mm under antecedent rainfall effects. The compacted catchment with local soils has a great potential for rainfall harvesting in the semiarid regions of China, but soil erosion is a problem, some form of soil stabilization would be needed in future use.

Keywords: Rainwater harvesting; Microcatchment; Runoff; Infiltration

1. Introduction

Precipitation is the major water source for agricultural production in the semiarid loess regions of northwest China. In the drier part of the Loess Plateau, mean annual precipitation is between 250 and 350 mm with a 35% coefficient of variation and over 70% of the precipitation falls during the monsoon months between June and September (Li et al., 2001b). The most widespread land-use system in the region is rainfed farming. Rainfed cropland occupies about 80% of the total cultivated land (Shan, 1993). However, limited and erratic precipitation often results in low crop yields and sometimes in total crop failure. The rainy seasons usually do not coincide with growth stages for most crops, only 19–24% of rainfall occurs between May and June when the crop water requirement accounts for 60% of that of the total growing period (Li et al., 2001a). Furthermore, soil evaporation is most severe in the region, a water balance study on the dry sloping land of the Loess Plateau has shown that about 5–10% of the precipitation is lost as runoff, 45–50% is transpirated by plants and 45–50% is evaporated (Zhang and An, 1997). As a result, crop production is only 25–33% of the potential productivity and water use efficiency is between 0.5 and 0.6 kg m^{-3} due to water stress (Zhu and Li, 1997). The uncertainty of rainfall

* Corresponding author. Tel.: +86-931-8275593; fax: +86-931-8273894.

E-mail address: xxyyli@fm365.com (X.-Y. Li).

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forces farmers to adopt low-input crop management practices and thereby the yearly economic income was usually less than 100 US$ per capita. The links between the erratic rainfall, the low-input strategy, and low yield is a major impediment for improving crop yields. Due to the fact that higher and more stable yields require better availability of water to the crops, it is evident that some more effective practices are necessary to be taken to maximize utilization of precipitation by collecting rainwater and reducing unproductive evaporation (Li et al., 2001b).

Water harvesting, based on the collection of precipitation runoff from a prepared catchment surface and the storage in the adjacent crop area, has been used successfully for crop yield improvement in the arid and semiarid regions of the world for thousands of years (Bruins et al., 1986; Reij et al., 1988). Some examples were at Ur and other places in the Middle East as early as 8500 BP (Suleman et al., 1995). Researchers have reconstructed water-harvesting system used for runoff farming in Israel's Negev Desert 4000 years ago (Evenari et al., 1968). American Indians used similar systems 700–900 years ago in the southwestern US (Myers, 1975). Chinese farmers used flood diversion technique called 'Warping' (harvesting water as well as sediment) 2700 years ago in the China's loess areas (Li et al., 2000c). Most of these projects used trial-and-error for the design of catchment basin sizes and shapes (Suleman et al., 1995). The common types of catchments in use include microcatchments, strip harvesting, roaded catchments and harvesting aprons (Brooks et al., 1991). Microcatchments and strip harvesting can be successful in years of normal or above normal rainfall and are best suited for situations in which drought-resistant trees or other drought-hardy perennial species are grown (Brooks et al., 1991). Particularly, the microcatchment procedure can be used in complex terrain or on steep slopes, where other water-harvesting techniques may be difficult to install. In general, the larger the size of the catchment, the smaller is the percentage of runoff produced by a given storm (Ben-Asher et al., 1985). The runoff increased with increasing slope and decreasing slope length (Myers, 1974; Sharma et al., 1982; Evett and Dutt, 1985). In the case of microcatchments, the catchment size can range from 10 to 1000 m^2, depending upon the precipitation in the area and plant requirements. The sizes may be less than 5 ha for annual crops, 31–144 m^2 for jujube (*Zizyphus mauritiana* Lam.) orchards in India (Yadav et al., 1980; Ojasvi et al., 1999), 0.35 ha for fuelwood plantation in Israel (Zohar et al., 1988), 144–289 m^2 for fig, olive, pistachio plantation in Syria (Ibrahim, 1994). Microcatchment rainwater harvesting combined with mulches in the infiltration patches was found to be effective on tree growth and crop production (Gupta, 1995; Gupta et al., 1999; Ojasvi et al., 1999; Li et al., 2000d; Li et al., 2001b). Mulches can increase infiltration rate by intercepting and absorbing raindrop impact, and impeding lateral flow of excess surface water. Thus, it preserved the structure of immediate soil surface, held excess water in contact with soil surface longer and allowed more infiltration (Adams, 1966). Li et al. (2001b) reported that mulches in the infiltration basin increased the effectiveness of the harvested water by 8–25%.

In the semiarid regions of northwest China, a growing awareness of potential of rainwater harvesting for improving crop production arose with widespread droughts in the 1980s followed by serious shortages of drinking water and crop failures (Li, 2000; Li et al., 2000c). Rainwater harvesting was first practiced in Gansu Province of northwest China and aimed at solving drinking water problem for human beings and livestock. Since 1995, rainwater harvesting has been promoted by the government as a solution to the problem of water shortages for agricultural production and has been termed rainwater harvesting agriculture (RHA). (Cook et al., 2000; Li et al., 2000a; Li et al., 2001a). The RHA system consists of collection surface (catchment), runoff channel, sediment tank, storage container and supplemental irrigation system. The popular catchments for runoff concentration are rooftops, courtyards, earth and asphalt-paved roads. However, due to a small number of catchment types and local poor economic conditions, the current rainfall-harvesting practices in China are still confined to rural family units to supply household water needs and for limited supplemental irrigation purpose. Since the success of the runoff concentration depends in part upon the optimal characteristics of the microcatchment with respect to the surface treatments, more research is needed to select optimum catchment treatments characterized by low cost and simple operation for a large-scale use in the region.

Many water-harvesting catchment surface treatments

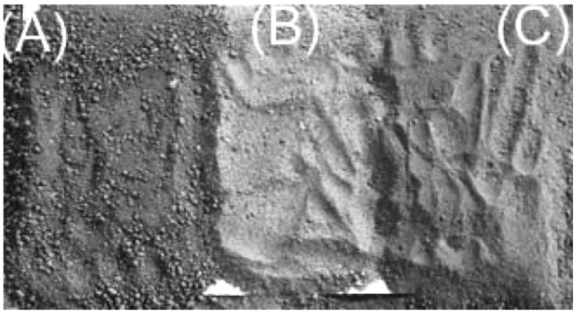

Fig. 1. Soils for the compacted catchments: (A) laterite; (B) fine sand; (C) loess.

for increasing runoff have been proposed and tested throughout the arid and semiarid regions of the world (USDA, 1975; Dutt et al., 1981; Evett and Dutt, 1985). These runoff inducement treatments include mechanical treatments (smoothing and compacting), colloidal dispersion methods (Slaking), hydrophobic applications (water repellents), surface binding materials (cementing and sealing) as well as surface covering (asphalt, rubber and plastic) (Tadmor and Shanan, 1969). Among these treatments, probably only the cheapest treatments involving clearing, smoothing and compacting are economical for crop production (Cluff and Frobel, 1978; Evett and Dutt, 1985). Sodium dispersed, compacted earth microcatchments had been tested and used in the USA (Frasier et al., 1987) and roaded catchments in Australia (Hollick, 1975). However, these water-harvesting techniques do not always transfer well from one set of conditions to another (Ojasvi et al., 1999). This paper was intended to study the effectiveness of runoff yield by determining runoff efficiency and threshold rainfall values, from compacted catchments with some local earth materials during naturally occurring rainfall events in the semiarid loess regions of northwest China.

2. Methods and materials

2.1. Climate

This study was conducted during the rainy period from 26 July, 1998 to 10 October, 1999 at the Gaolan Research Station of Ecology and Agriculture, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. The station is located in the transitional zone between arid and semiarid regions (Gaolan County, Lanzhou, Gansu Province, 36° 13″N, 103° 47″E) at an altitude of approximately 1780 m. Mean annual precipitation is 263 mm, nearly 70% falling between May and September. Mean annual temperature is 8.4 °C with a maximum temperature of 20.7 °C (July) and a minimum of −9.1 °C (January). Average annual pan evaporation is 1785.6 mm. The soil is a sandy loam (sand 12.3%; silt 66.9%; clay 20.8%) of loess origin which belongs to Haplic Orthic Aridisols (Li et al., 2000b).

2.2. Experimental design and treatments

The soils for the compacted catchment construction are the mixture of the late quaterary loess, tertiary laterite and fine sand (Fig. 1). The soil composition (0–20 cm) and some properties of the loess and laterite are listed in Table 1. The loess soil is classified as Haplic Orthic Aridisols and laterite soil as Red Orthic Entisols according to the Chinese Soil Taxonomy. The loess is the zonal soil with deep depth in this region and the laterite is its underlying sediments, which locally called red clay soil with low infiltration. The laterite is often used for seepage control, and easy to crack when exposed to sun drying. The grain size composition of fine sand comprises >2 mm: 9.80%; 0.05–2 mm: 87.7% and <0.05 mm: 2.50%. The addition of fine sand is to reduce shrink actions of the red clay soil for decreasing initial rapid water entry under the rain. In general, the soil water content was 16% (by weight) when the soil surface layer was near saturation for the compacted mixed soil and 20% for the untreated loess soil. As this study is a part of the researches on the selection of catchment types suitable for large-scale use in the region, which involved many kinds of surface treatments, there were two replicates for each treatment. However, great care was paid to the site selections and catchment preparations for homogeneous treatments between replications. Furthermore, results would be discarded for differences between two replications within the same treatment beyond 5% error limits. There are two treatments in this study, i.e. compacted treatments with local earth materials and undisturbed bare loess catchments. Four 3.3 by 6.0 m runoff plots with their longer sides parallel to the slope (14%) were used to

Table 1
Selected physical and chemical properties of the loess and laterite used in the experiment

	Sand, 2–0.05 mm	Silt, 0.05–0.002 mm	Clay, <0.002 mm	Organic content (g kg^{-1})	Cation exchange (Cmol kg^{-1})	Bulk density (g cm^{-3})	pH	$CaCO_3$ (%)
Loess	23.7	60.0	16.3	19.4	9.2	1.3	8.7	22.7
Laterite	10.9	70.7	18.5	6.5	8.2	1.4	8.5	7.9

measure runoff. Cement block borders, 30 cm high, were installed around each plot to define the catchment areas and to improve the accuracy of runoff measurements. Two runoff plots were constructed using the uniformly mixed above-mentioned soils at the ratio of 1:1:1 and the thickness was 8 cm. The mixed soils were first wetted by spraying water, then compacted with many passes of a roller, the topsoil surface penetration resistance reached 84.69 kg cm^{-2} with a bulk density of 1.75 g cm^{-3}. The other two undisturbed bare loess slope runoff plots were left as controls. Runoff from each plot was collected in a 200-l calibrated barrel, covered with a close fitting plastic sheet to prevent catching precipitation and to prevent evaporation of the collected runoff water. A photograph showing compacted catchment layout is presented in Fig. 2. The runoff was measured after each rainstorm or twice daily during continuous rainfall events. A standard rain gauge and recording rain gauge were used to obtain the amount and intensity of the rainfall. A double-ring infiltrometer was used to determine infiltration rate for the treated and untreated soil under ponded conditions. Saturated hydraulic conductivity and parameters of permeability for the treated and untreated catchments were measured using Guelph permeameter (Model 2800). The rainfall–runoff efficiencies (percent of the rainfall) and threshold rainfall amounts (minimum rainfall required to produce runoff) for moist and dry soil surface were determined using linear regression analysis of the separate rainfall events as described by Frasier (1975) and Diskin (1970). Regression analysis was done using SPSS procedure.

Fig. 2. Layout of the compacted catchment with loess, laterite and fine sand.

3. Results and discussions

3.1. Rainfall and runoff characteristics

From 26 July, 1998 to 10 October, 1999, there were 70 rainfall events. The distribution of daily rainfall and rain intensity is presented in Fig. 3 and Table 2. Sixty percent of the rainfall events were of less than 5 mm and 79% were of less than 5 mm h^{-1} (I_{30}). Furthermore, the data analysis also indicated that about 60% of the total amount of the annual rainfall resulted from over 10 mm rainstorms. Rainfall intensity were generally higher for high values of rainstorms, the correlation coefficient of rainfall and rain intensity was 0.587 ($F_{(1,67)} = 37.72$, $P < 0.0001$). The results suggest that most storms were of small size with low intensity, but the total amount of annual rainfall mainly depended on a few of lager size storms, which characterized the monsoon period in the region.

Among the 70 rainfall events, 40 produced a total runoff of 156.6 mm from the compacted plots, while only 28 produced 41.6-mm runoff from the control plots. The monthly distribution of rainfall and runoff from the compacted plots and the control plots are indicated in Fig. 4. The average runoff efficiency was calculated by dividing the total volume of runoff

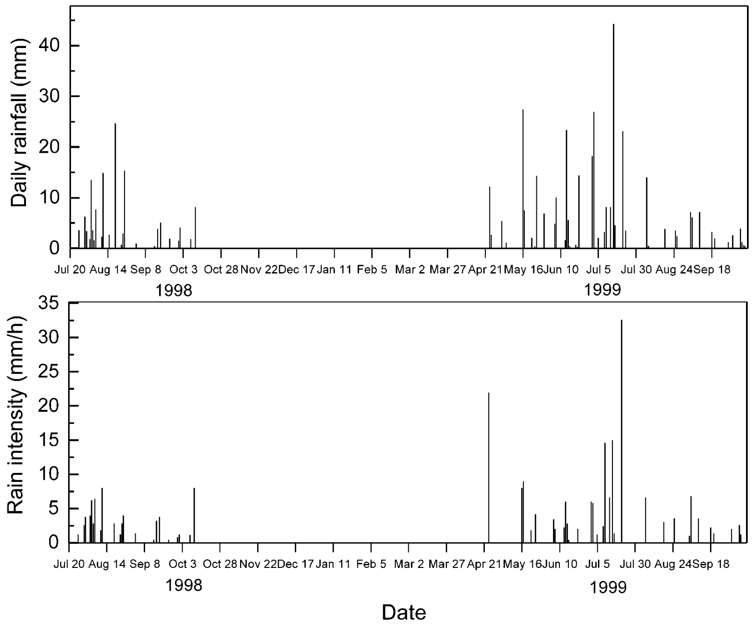

Fig. 3. Daily rainfall and rain intensity distribution during the experimental period.

by the total volume of rainfall, which fell over the plots. The compacted treatments produced a higher rate of runoff and the average runoff efficiency (runoff/rainfall) reached 33%, while the average runoff efficiency of the controls was very low, only 8.7% during the experiment period. Runoff from both the compacted plots and the control plots increased with the increase in the amount and intensity of the rainfall (Table 3). Runoff and the amount and intensity of the rainfall were significantly correlated; the correlation coefficient of the runoff and the amount of the rainfall was 0.95 for the compacted plots and 0.72 for the control plots. However, the correlation coefficient of runoff and the rainfall intensity was 0.63 for the compacted plots and 0.86 for the control plots. Runoff efficiencies of both the compacted plots and the control plots also increased with the increase in the amount and intensity of the rainfall (Table 3). Multiple regression equations of runoff with the rainfall amount, intensity and duration set out in Table 3 indicated that runoff increased as 49% for the compacted plots with the increase in the rainfall and 8.4% for the control plots. Increase in the intensity resulted in increase in the runoff by 5.1% of the total rainfall intensity for the compacted plots and 15.5% for the control plots. This suggests that runoff during particular rain spell was more governed by the size of the rainstorm for the compacted microcatchments than for the untreated microcatchments. Runoff generally decreased with the increase in the rainfall duration for both the treatments. Rainfall intensity played a dominant role in increasing runoff efficiency from the microcatchments. Increase in the intensity of rainfall increased runoff efficiency by 153% of the

Table 2
Frequency distribution of rainfall amount and intensity in various class intervals during the experimental period

	Rainfall amount (mm)				Rainfall intensity, I_{30} (mm h^{-1})		
	< 5	5–10	10–20	> 20	< 5	5–10	> 10
Percentage (%)	60	18	12	10	79	15	6

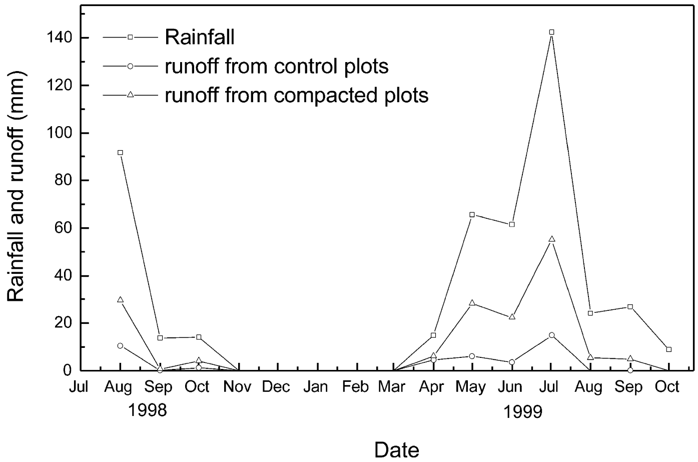

Fig. 4. Monthly distribution of rainfall and runoff for the compacted and control plots during the experiment period.

increase in the intensity for the compacted microcatchments and 124% for the control microcatchments. However, for increase in the rainfall, the increase in runoff efficiency was only 101% of the increase in the amount of the rainfall for the compacted microcatchments and 66.1% for the controls. This was due to runoff occurred as rainfall-excess or infiltration-excess overland flow process whereby the rainfall rate exceeded the infiltration rate of the soil. The total runoff was mainly depended on fewer single storm of high intensity (Li, 2000). Table 3 also indicates that runoff efficiency increased with an increase in rainfall duration for the compacted microcatchments, while decreased with an increase in rainfall duration for the controls.

Runoff observations were also undertaken at intervals of about 20 min during the rainfall events of 1 and 2 July, 1999. There had been no rain for successive 20 days before July 1, so runoff-producing process in rainy days of July 1 and 2 would represent runoff with and without antecedent rainfall effect, respectively. Fig. 5(A) shows cumulative rainfall and runoff from both the compacted plots and the control plots measured during the rain of July 1. This rain lasted 5.66 h and the total amount was 18.2 mm. Runoff produced in the control plots only within 40 min of the onset of rainfall with a high intensity of 7.8 mm h^{-1}. In contrast, intermittent runoff production occurred in the compacted plots.

Table 3
Regression equations (P, daily rainfall (mm); R, daily runoff (mm); R_e, runoff efficiency (%); I, rainfall intensity (mm h^{-1}); D, rain duration (h); r, correlation coefficient; linear regression analysis was based on 70 data pairs apiece for both treatments) and coefficient values between runoff and rainfall, intensity and duration

Treatment	Equation	r	F value	Significance level
Compacted	$R = -1.022 + 0.487P$	0.945	572.000	< 0.0001
Untreated	$R = -0.238 + 0.122P$	0.716	71.403	< 0.0001
Compacted	$R_e = 3.717 + 1.768P$	0.699	64.942	< 0.0001
Untreated	$R_e = 0.818 + 0.480P$	0.430	15.422	< 0.0001
Compacted	$R = 0.476 + 0.494I$	0.626	42.637	< 0.0001
Untreated	$R = -0.231 + 0.228I$	0.855	178.987	< 0.0001
Compacted	$R_e = 7.050 + 2.483I$	0.632	43.961	< 0.0001
Untreated	$R_e = -0.566 + 1.292I$	0.741	80.454	< 0.0001
Compacted	$R = -0.931 + 0.493P + 0.0509I - 0.0978D$	0.951	201.677	< 0.0001
Untreated	$R = -0.295 + 0.0837P + 0.155I - 0.0610D$	0.900	90.521	< 0.0001
Compacted	$R_e = 1.406 + 1.014P + 1.530I + 0.500D$	0.749	27.286	< 0.0001
Untreated	$R_e = -0.0942 + 0.0661P + 1.242I - 0.181D$	0.743	26.217	< 0.0001

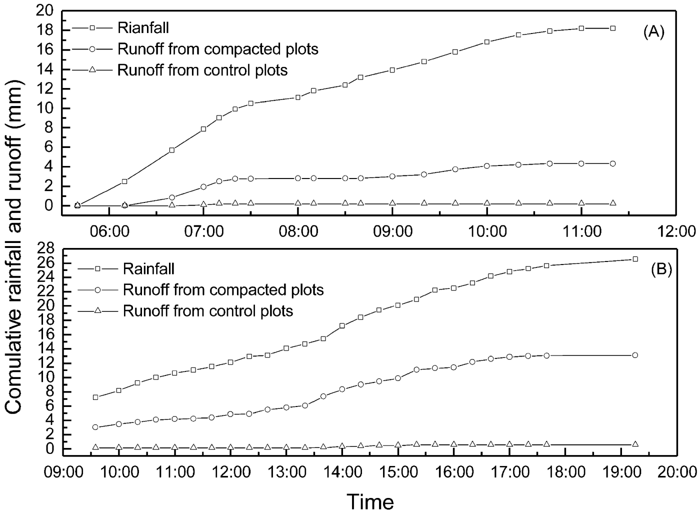

Fig. 5. Cumulative rainfall and runoff from both the compacted and control plots measured during the rain of: (A) July 1; (B) July 2.

There was no runoff only in the interval of 7:30–8:30 with a rainfall of 1.8 mm when the rain last 1.8 h. Runoff behavior was different for the compacted treatments during 26.5 mm rainfall with a duration of 11.50 h on July 2 (Fig. 5(B)). Runoff produced continuously from the compacted plots with a runoff efficiency of 49% as compared to 24% on July 1. While the runoff of the control plots generated only in the higher intensity stage (13:30–16:00) when the rain last about 4 h. Runoff efficiency was 1.1% during the rain of July 1, and increased twofold on July 2. The results demonstrate that the compacted catchments with such local soils can significantly increase runoff efficiency as compared to the controls, especially when the surface was wetted, and that the antecedent soil moisture had a great effect on the runoff generation.

The reasons for higher runoff yield of the compacted catchments with local soils were mainly attributed to their low permeability. Table 4 indicates that the field-saturated hydraulic conductivity of the controls is 13 times higher than that of the compacted catchments. Compacted catchments have a lower matric flux, soil sorptivity and field-saturated volumetric water content and a higher bulk density as compared to the controls. Fig. 6 shows the infiltration rate curve of the compacted and control treatments under the ponded conditions. The initial infiltration rate of the compacted mixed soils is 10% of that of the natural loess (control), and the final constant infiltration rate is only 1% of the control.

The low permeability of the compacted catchments may be due to the effects of the compaction and soil particle composition. Compaction made surface soil layers achieve higher soil density, thus diminishing the seepage losses. Also, compacted soils may contain appropriate ratio of the content of sand to the content of clay. Higher clay contents can lead to surface cracking under dry conditions, while sand can mitigate clay cracking. Kemper and Noonan (1970) reported the highest runoff from soils with 50–80% sand in laboratory studies of soils subjected to repeated wetting and dry cycles. The last but not the

Table 4
Saturated hydraulic conductivity and parameters of permeability (K_{fs}, field-saturated hydraulic conductivity; Φ_m, matric flux; S, soil sorptivity; α, alpha constant; Θ_i, initial volumetric water content; Θ_{fs}, field-saturated volumetric water content) for the compacted and control catchments

Treatment	K_{fs} (cm s^{-1})	Φ_m (cm^2 s^{-1})	S (cm s$^{-1/2}$)	α (cm^{-1})	Θ_i (cm^3 cm^{-3})	Θ_{fs} (cm^3 cm^{-3}	Bulk density (g cm^{-3})
Compacted	4.05×10^{-5}	1.17×10^{-3}	0.022	0.035	0.062	0.27	1.75
Untreated	5.34×10^{-4}	1.87×10^{-3}	0.029	0.29	0.070	0.30	1.38

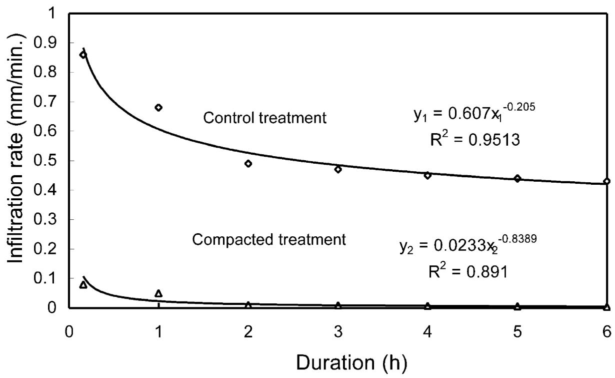

Fig. 6. Infiltration rate curve of the compacted and control treatments under the ponded condition.

least crust formation during the rain is also responsible for low permeability and thereby high runoff yield for the compacted catchments. Raindrops can detach and breakdown the soil aggregate of such compacted catchment easily, the clay particles migrate with the infiltrating water to clog the soil pores and form a surface seal. The crust formation after rain for the compacted catchments is presented in Fig. 7. The infiltration rate dropped sharply after the crust was formed and the soil surface was easily saturated, thus achieving a higher runoff efficiency. A good case in point is the above-mentioned rainfall events of 1 and 2 July, 1999. The infiltration rate fell off rapidly within 20–30 min after runoff begin, and then achieved a steady state infiltration of approximately 0.025 mm min^{-1} for both the rainfall events.

3.2. Threshold rainfall

Linear regression analysis of runoff per storm against storm size (Hillel, 1967; Frasier, 1975; Fink and Frasier, 1977) was used to get the threshold rainfall (i.e. the minimum precipitation required to produce runoff). If infiltration rates are low, then a model of the form

$$Q = B_1(P - B_2) + \varepsilon \tag{1}$$

can sometimes be usefully fitted to daily-runoff data (Evett and Dutt, 1985), where P is the rainfall depth (mm), Q, the runoff depth (mm), B_1, the runoff efficiency, B_2, the threshold rainfall depth (mm), and ε the error term (Frasier, 1975; Myers, 1963; Evett and Dutt, 1985). However, Diskin (1970) showed that inclusion of all data, including zero runoff events, while fitting Eq. (1) tended to give values of B_1 and B_2 that were lower than the true efficiency and threshold values. His two-part model for determining threshold rainfall for this case was listed as follows:

$$Q = \begin{cases} 0 + \varepsilon & P < B_2 \\ B_1(P - B_2) + \varepsilon & P \geq B_2 \end{cases} \tag{2}$$

The procedures for determining threshold rainfall began with the setting of an arbitrary value for B_2 and proceed through a two-step iteration (Evett and Dutt, 1985):

1. The sum of squared deviations of runoff values from the line $Q = 0$ was calculated for data pairs for which $P < B_2$, and this sum was added to the sum of squared deviations of runoff values from the

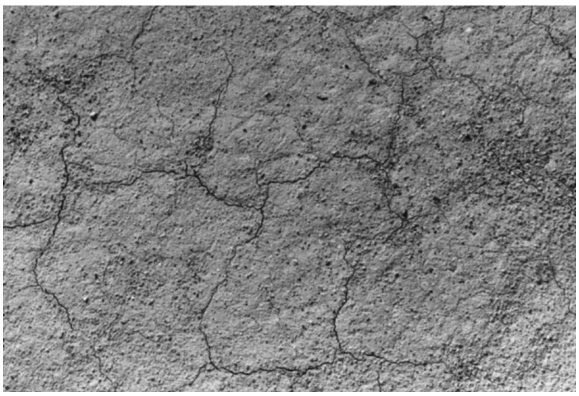

Fig. 7. Crust formation after rain for the compacted catchments.

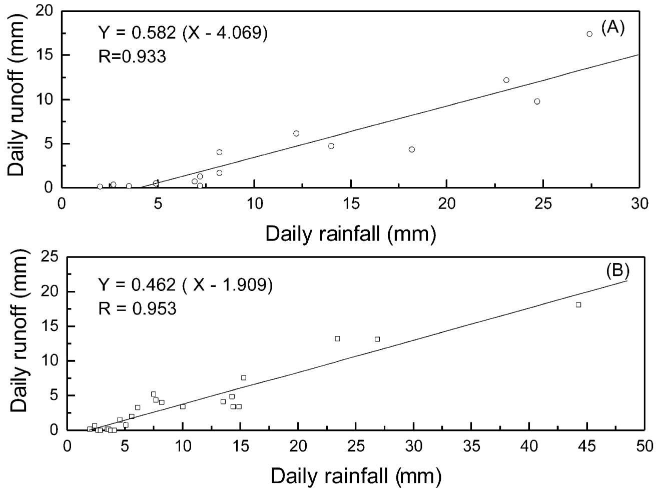

Fig. 8. Linear regression line for the determination of threshold rainfall for the compacted catchments: (A) no antecedent rainfall effect; (B) with antecedent rainfall effect.

least squares linear regression line, $Q = B_1(P - B_2)$ (where B_2 is now fixed), fitted to data pairs for which $P \geq B_2$.

2. The value of B_2 was increased by a small amount and Step (1) was repeated.

Iteration proceeded until the minimum total sum of squares was found and the corresponding values of B_1 and B_2 were taken as the best estimates. Since many daily runoff values were zero or nearly zero for natural loess catchment (control) in the experiment, the threshold rainfall of the control catchments was determined by Eq. (2). The threshold rainfall of compacted catchments was determined by Eq. (1).

Antecedent soil moisture has obvious effect on the runoff yield for earth catchments. Jain and Singh (1980) reported that minimum threshold values of rainfall for inducing runoff from runoff strips of medium texture soils were found to vary between 3 and 5 mm for moist surfaces and 7 and 9 mm for dry surfaces. In the study area, the authors noticed that when the soil is dry, the water content of the upper 20-cm soil layer average 7.5% (by weight) for the control plots and 5.6% for the compacted plots. But when the soil is wet, the water content of the upper 20-cm soil layer average 20.1% (by weight) for the control plots and 16.9% for the compacted plots. To explore the effect of antecedent rainfall on the threshold rainfall values for the compacted catchments, the two adjoining rainfall events with over 3-day interval were regarded as rains with little antecedent rainfall effects in the data analysis and the corresponding catchment surfaces was regarded as dry surfaces. While two adjoining rainfall events with 1-day or less than 1-day interval were considered rains with antecedent rainfall effects and the corresponding catchment surfaces was regarded as moist surfaces.

The results of the data analysis indicate that the threshold rainfall is 8.5 mm for the control catchments under no antecedent rainfall effects and 6 mm under antecedent rainfall effects. This quantity includes depression and interception storage, initial infiltration and evaporation before runoff begins. Daily rainfall correlated well with daily runoff for the compacted catchments (Fig. 8), the linear regression equation showed that the threshold rainfall for the compacted catchments was 4.0 mm under no antecedent rainfall effects and 1.9 mm under antecedent rainfall effects. This means that the minimum precipitation required to produce runoff reduce about 4 mm due to the compaction of the mixed soil treatments as compared to the controls and the antecedent rainfall affect runoff about 2.0–2.5 mm during an individual rainfall event. Data analysis also showed that when the soil surface was dry, the average runoff efficiency was 8.1% for the control catchements and 26.6% for the compacted catchments. When the soil surface was moist, the average runoff efficiency was 10.4% for the control catchements and 37.6% for the compacted catchments.

4. Conclusions

The compaction combined with local soils for the construction of the water-harvesting catchments, is an effective means of reducing infiltration and improving runoff yield. Thus, such compacted catchment with local earth material available has a great potential for rainfall harvesting in the semiarid regions of China. In comparison with the undisturbed loess slope (control), runoff-producing rainfall events would increase about 13, 8 and 6 days in the wet, average and drought rainfall years for the compacted catchments in the study area based on the analysis of the 10-year rainfall data. The average runoff efficiency was 33% for the compacted microcatchments with mixed soils and 8.7% for the controls. Thus, in the drought years a water yield of about 500 $m^3 ha^{-1}$ may be expected from the compacted catchments, 860 $m^3 ha^{-1}$ in the average years and about 1110 $m^3 ha^{-1}$ in the wet years.

Compaction is cheap and uses readily available equipment. Costs for the compacted mixed-soil catchment are highly variable depending upon actual site conditions, available material, labor and equipment. Taken as a whole, the total cost for the compacted catchments is about 0.9 yuan m^{-2} (1 yuan is equal to about 0.12 US$) in the experiment, of which material cost is 0.3 yuan m^{-2} and labor cost is 0.6 yuan m^{-2}. With an average runoff efficiency of about 30%, the cost of the collected water in a 300-mm rainfall zone is 0.10–0.84 yuan m^{-3}. In contrast, the common concrete catchment in use in northwest China costs 5.3 yuan m^{-2} including 3.5 yuan material cost and 1.8 yuan labor cost. The cost of the collected water for concrete catchment in a 300-mm rainfall zone is 2.56–3.82 yuan m^{-3} (Li, 2000). Due to the poor living conditions in the semiarid regions of northwest China, labor cost is often inexpensive, and farmer would invest little for such compacted catchment construction if the materials were available.

The disadvantage of the compacted catchments was the serious soil erosion problem under the high intensity rainfall (see Fig. 2). The sediment concentration is about 0.6 g l^{-1} under the light rain, while 74.5 g l^{-1} under the high intensity rainfall ($I_{30} > 15$ mm h^{-1}). So some form of soil stabilization would be needed in future use.

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