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Influence of Gravel Mulch on Rainfall Interception under Simulated Rainfall

Yang QIU, Zhongkui XIE and Yajun WANG*

Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou, P.R. China

**Corresponding author: wxhcas@lzb.ac.cn*

Abstract

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To understand the hydrological outcomes of interception by gravel mulches, rainfall simulation experiments were conducted in the loess regions of northwestern China. The rainfall interception decreased with gravel size but increased with the thickness of the gravel mulch layer, following two exponential functions. Interception was 15.1% of the gross rainfall at 1 cm thickness, followed by 17.2, 20.9, 30.5 and 45.6 % at 3, 5, 7 and 10 cm thickness, respectively. For the equivalent gravel grain size of 3.43 mm, relative interception was 45.6%, which was about 1.1, 1.2, 1.4 and 2.3 times higher than that for the equivalent grain size of 11.01, 19.31, 32.8 and 43.72 mm, respectively.

Keywords: gravel; interception; loess plateau; rainfall simulation

Rainfall intercepted, stored and subsequently evaporated from gravel mulch can be termed as interception of gravel mulch (Li *et al.* 2000). Gravel mulch is a traditional water-conservation technique that has been used for over 300 years in the Loess Plateau region of northwestern China. Many studies showed a gravel mulch to be effective in reducing evaporation and increasing soil temperature (Lightfoot & Eddy 1994; Yuan *et al.* 2009; Xie *et al.* 2010; Ma & Li 2011; Qiu *et al.* 2014). Yuan *et al.* (2009) reported that gravel mulches reduced evaporation by 49.1 to 83.6% compared with the bare soil. However, little work has been carried out on rainfall interception loss by a gravel mulch layer itself. A field study of rainfall interception during naturally occurring rainfall events revealed that rainfall interception by a gravel mulch accounts for 14–36% of rainfall (Li *et al.* 2005). This highlights the importance of estimates of interception losses by gravel mulches. However, the interception losses by gravel mulches are difficult to measure precisely in the field during naturally occurring rainfall events, because the ignored evaporation during the natural rainfall events would bring deviation and the rainfall intensity effects were not considered. The objective of this research is to quantify the interception losses by gravel mulches in response to varying gravel size, thickness and rainfall intensity under simulated rainfall.

MATERIAL AND METHODS

This study was conducted at the Gaolan Research Station of Ecology and Agriculture, Chinese Academy of Sciences (36°13'N, 103°47'E). Measurements of rainfall interception by gravel mulches were done according to methods proposed by Li *et al.* (2000). The gravel-mulch storage capacity was determined by the method of Leyton *et al.* (1967). A 2 × 3 m steel tank with its longer sides parallel to the slope (15 %) was used to measure runoff. In our study, we used equivalent grain size (d_i) to describe the gravel samples, assuming the gravels are all spheroid, and the d_i is the diameter of the corresponding equivalent sphere.

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Table 1. Some characteristics of the selected gravel samples

Gravel type	Grain size distribution (mm)	d_i	P_t (%)	SSA (m^2/kg)
A	2–5	3.43	44.15	44.15
B	5–20	11.01	44.07	44.07
C	20–40	19.31	43.76	43.76
D	40–60	32.89	44.52	44.52
E	60–80	43.73	42.15	42.15

d_i – equivalent grain size; P_t – total porosity; SSA – specific surface area

We used five types of gravel mulch with different equivalent grain size (d_i): (A) 3.43 mm, (B) 11.01 mm, (C) 19.31 mm, (D) 32.89 mm and (E) 43.73 mm (Table 1). In addition, we included three mixed treatments: mixture of A and E 1:1 by volume (M1), mixture of B and E 1:1 by volume (M2) and mixture C and D 1:1 by volume (M3). The thickness is 10 cm for these 8 treatments. Besides, we used gravel (d_i = 3.43 mm) layers with thickness of 1, 3, 5, 7 and 10 cm. A rainfall simulator (QYJY-501, Qingyuan Measurement and Control Technology Co., Ltd., P.R. China) was used to simulate rainfall. The simulator produced 2.3 mm raindrops at a height of 5 m to generate storms. In order to evaluate the influence of gravel size and thickness on rainfall interception, 6 rainfalls were simulated for each treatment: 15, 30 and 45 min with rainfall intensity of 20 and 30 mm/h. And for A treatment, five rainfall intensities were established (20, 30, 40, 50 and 60 mm/h) to evaluate the influence of rainfall intensity in the same gross rainfall (30, 20, 15, 12 and 10 minutes rainfall duration, respectively) on interception. There were three replications for each rainfall.

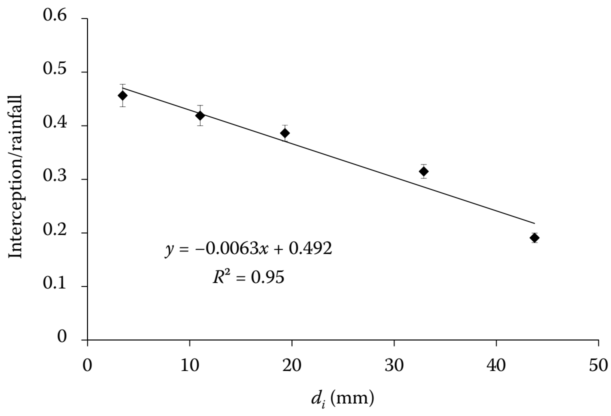

Figure 1. Relationship between relative interception (interception/rainfall) and pebble size

RESULTS AND DISCUSSION

Relative interception decreased with gravel size following a linear function (Figure 1) but increased with gravel mulch thickness (Figure 2), following an exponential function. Relative interception was 15.1% at 1 cm thickness, followed by 17.2, 20.9, 30.5 and 45.6 % at 3, 5, 7 and 10 cm thickness of gravel mulch, respectively. For the equivalent gravel grain size of 3.43 mm, relative interception was 45.6%, which was about 1.1, 1.2, 1.4 and 2.3 times higher than that for the equivalent grain size of 11.01, 19.31, 32.8 and 43.72 mm, respectively. This result was in agreement with the previous study, which revealed that rainfall interception by gravel mulch decreased with the gravel size in natural rainfall (Li *et al.* 2005).

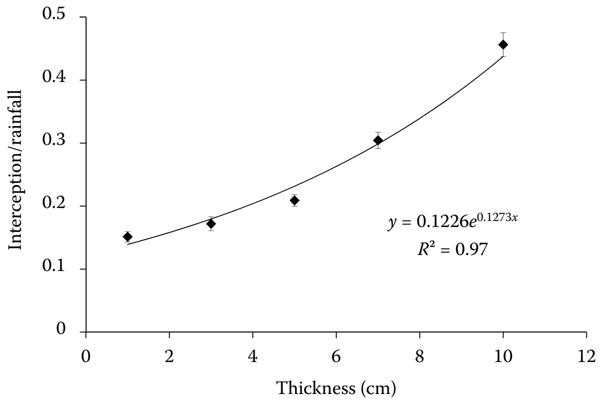

Figure 2. Relationship between relative interception (interception/rainfall) and thickness

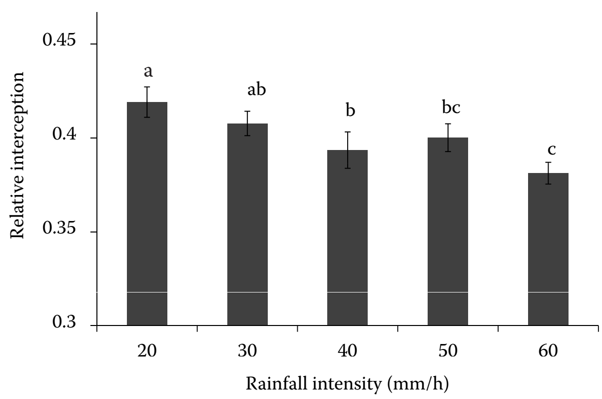

Figure 3. Relative interception (interception/rainfall) under different rainfall intensity; bars in the graph labelled with different letters differ significantly ($P < 0.05$)

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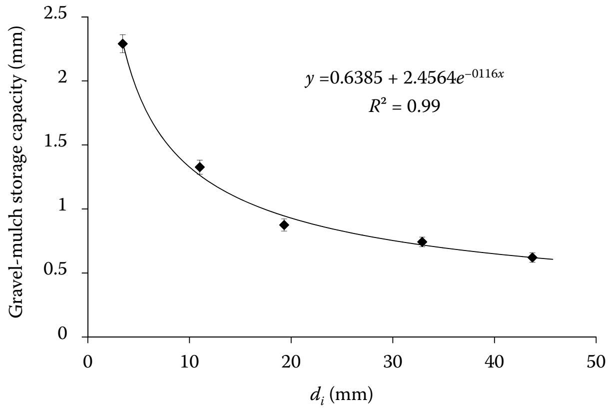

Figure 4. Relationship between gravel-mulch storage capacity and pebble size

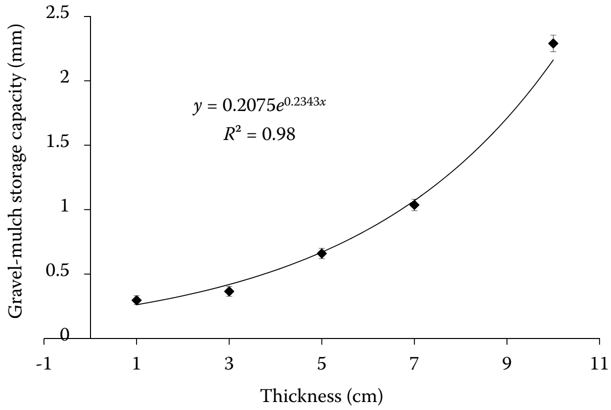

Figure 5. Relationship between gravel-mulch storage capacity and thickness

Relative interception generally decreased with increased simulated rainfall intensity (Figure 3). The differences in relative interception at rainfall intensity 30, 40, 50 mm/h were not significant. However, the relative interception at rainfall intensity 20 mm/h was significantly higher than that at 60 mm/h. El Boushi and Davis (1969) reported that rainwater intercepted by rock fragments will be retained as a thin film on the stone surface, in capillary openings at contact points between stones, and in small puddles on the upper side of stones. Low rainfall intensity may protect the water in capillary openings at contact points between stones and the small puddles on the upper side of stones.

Gravel-mulch storage capacity decreases with gravel sizes (Figure 4), but increases with the thickness of the gravel mulch layer (Figure 5). The gravel-mulch storage capacity was 0.29 mm at 1 cm thickness, followed by 0.37, 0.66, 1.04 and 2.29 mm at 3, 5, 7 and 10 cm thickness, respectively. For the equivalent gravel grain size of 3.43 mm, the gravel-mulch storage capacity was 2.29 mm, followed by 1.33, 0.87, 0.74 and 0.62 mm for the equivalent grain size of 11.01, 19.31, 32.8 and 43.72 mm, respectively. The relationship between gravel-mulch storage capacity and the d_i of gravel can be represented by an exponential curve. The gravel-mulch storage capacity of fine gravel (d_i = 3.43 mm) tended to be much higher than in the others, this may be due to the larger specific surface area of fine gravel. The relationship between gravel-mulch storage capacity and the thickness of the gravel mulch layer can also be represented by an exponential curve. The total storage capacity of the mixed treatments was between the storage capacities of the two constituent parts (Figure 6). When the gravel size difference is not large, the calculated storage capacity was very close to the measured value, but when the gravel size difference is larger, the calculated storage capacity was significantly higher than the measured value (Table 2). This result indicated

Table 2. The calculated and measured gravel-mulch storage capacity of three mixed treatments

Treatment	H	d_i	S_c measured	S_c calculated
		(mm)		
M1	0.1	3.92	1.65	2.19
M2	0.1	13.56	0.98	1.14
M2	0.1	22.48	0.81	0.82

d_i –equivalent grain size; H – thickness; S_c – storage capacity

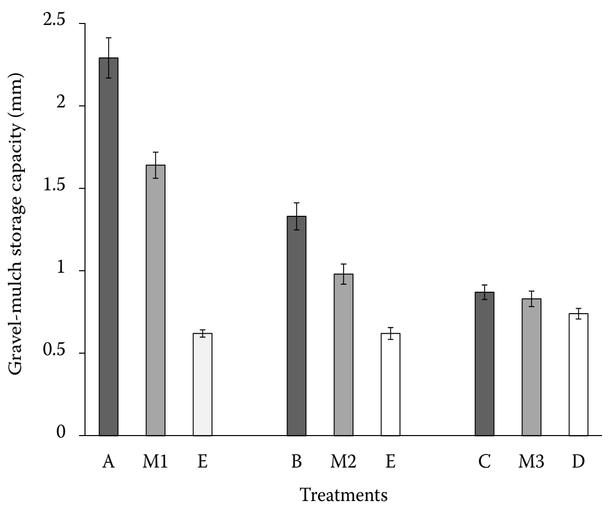

Figure 6. Gravel-mulch storage capacity of mixed treatments: M1 (mixture of A and E), M2 (mixture of B and E) and M3 (mixture C and D)

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that although the equivalent grain size can describe the gravel character in a single gravel size treatment, it cannot precisely describe the complex change of gravel structure in a mixed treatment.

CONCLUSIONS

The rainfall interception decreased with gravel sizes but increased with the thickness of the gravel mulch layer, and both relationships between storage capacity and gravel size, mulch thickness can be represented by an exponential function. The highest interception loss was seen in 10 cm thickness and 3.43 mm equivalent gravel grain size in this study (2.29 mm or 45.64%). To fully understand the mechanism of rainfall interception in a mixed gravel mulch layer, further research is needed.

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