Journal of Arid Environments 75 (2011) 432–437

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Water accumulation in soil by gravel and sand mulches: Influence of textural composition and thickness of mulch layers

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ARTICLE INFO

Article history:
Received 13 May 2010
Received in revised form
24 November 2010
Accepted 21 December 2010
Available online 19 January 2011

Keywords:
Gravel mulch
Runoff
Sand mulch
Soil water storage
Texture
Thickness

ABSTRACT

The use of gravel and sand as mulch has been an indigenous farming technique for crop production for over 300 years in the semiarid loess region of northwest China. The objective of this study was to determine the influence of texture and thickness of gravel and sand mulch layers on soil water storage by field experiments. The texture experiment consists of three commonly used gravel mulch types: pebble, mixed pebble and sand, fine sand; and the thickness experiment consists of 1, 2 and 3-layers of 2 cm pebbles. Each treatment has three replications. The results indicate that gravel–sand mulches were more effective in conserving soil water, as compared with the bare soil treatment, and the mixed pebble and sand mulch was more effective to conserve soil water than the sole pebble or sand mulch. Soil water content increased with mulch thickness (the number of gravel layers), 1-layer treatment had an average soil water content of 10.85% at 0–60 cm soil layer after a rainfall of 10 mm, 2.42% and 4.92% less than the 2-layers and 3-layers treatments. From May to October in 2004, two and three layers of pebbles conserved 9.8 ± 6.6 mm and 20.0 ± 14.3 mm more water, respectively, as compared with the one layer of 2 cm pebbles at the soil depth of 0–100 cm.

1. Introduction

Drought occurs in many parts of the world every year, often with devastating effects on crop production (Glantz, 1987). Water limitation is one of the major constrains affecting cereal production in rainfed agriculture (Mathews and Cole, 1938). In order to reduce water loss in arid and semiarid regions, mulching is a common and effective practice, and the materials for mulching include straw, gravel, sand, wood-shaving, grass, plastic and so on (Amir and Sinclair, 1996; Chiroma et al., 2006; Hou et al., 2010; Jiménez et al., 2005; Li et al., 2000; Materechera, 2009).

As one of the most important traditional techniques that are still practiced, gravel mulches have been used by farmers in dry areas of Argentina, China, Israel, Italy, Peru, New Zealand and USA for many years (Doolittle, 1998; Li, 2003; Lightfoot, 1994; Pérez, 2000; Poesen and Lavee, 1994). Studies by Alderfer and Merkle (1943) and Findeling et al. (2003) indicated that runoff was dramatically reduced by mulch in a moderately heavy rain (7.5 cm hr^{-1}), and bare soil plots lost 40–60% of incoming rainfall to runoff, while pebble mulch gardens lost only 3–10%. Lightfoot and Eddy (1994) noted that lithic mulch could reduce soil erosion and increase water infiltration significantly, especially during periods of drought. Yuan et al. (2009) reported that gravel mulches reduced 49.1–83.6% evaporation, as compared with the bare soil. According to the changes of the hydrological process, surface gravel mulches provide a more favorable environment for plant growth than non-mulched fields in arid and semiarid areas (Li, 2003).

Gravel mulches are effective to reduce water loss, but their efficiency varies widely, depending on mulch characteristics: position, cover, color, thickness, particle size and texture (Fairbourn, 1973; Kemper et al., 1994; Pérez, 1998, 2000; Poesen et al., 1990; Yuan et al., 2009). For thickness, previous studies reported that thicker mulch tend to reduce more evaporation than thinner one (Diaz et al., 2005; Hanks and Woodruff, 1958; Kemper et al., 1994). However, there is a threshold of mulch thickness to avoid excessive water interception by the gravel during low-intensity precipitation (Pérez, 2000). For size and texture, Modaihsh et al. (1985) showed that fine sand was not as effective in reducing soil water evaporation as coarser sands and gravels, Pérez (2000) noted that coarse lapilli (13.8 mm) were less effective than fine ash (2.9–3.8 mm) in preventing water loss, while medium-grained cinder (4–5.2 mm) produced the greatest water savings,

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doi:10.1016/j.jaridenv.2010.12.017

Xie et al. (2006) revealed that evaporation increased linearly with gravel size, Yuan et al. (2009) revealed that the evaporation reduction rates under gravel mulches were negatively correlated with gravel sizes, under the same soil water content. In summary, the influence of thickness and textural composition of gravel mulches on soil water conservation was still uncertain, and it is essential to determine a suitable thickness and textural composition for practice, based on field experiments.

Limited precipitation and severe evaporation in the semiarid loess region of northwest China often result in low crop yields and sometimes in total crop failure. In order to conserve the sporadic and limited rainfall for reliable crop production, gravel–sand mulches have been used as a surface barrier to reduce evaporation and thereby conserve soil water for over 300 years (Li, 2003). Moreover, rich gravel and sand deposits, and long last time of gravel–sand mulches facilitate the spread of such practices in the western part of the loess Plateau (Li, 2003). In 1990s, 118000 ha of such fields were distributed in Gansu Province, China. Based on the practice, there are three types of gravel and sand mulches in terms of texture composition: pebble, mixed pebble and sand, fine sand. The uniformly mixed gravel and sand mulches are widely used by local farmers and are considered as ideal mulching materials. However, until now, few field experiments were conducted to investigate how the texture composition and thickness of gravel–sand mulches affect soil water conservation in these areas; we do not know which mulching type and what thickness are the best for use. Therefore the objective of this study was to elucidate the effect of texture and thickness of gravel and sand mulch layers on runoff and soil water storage in the semiarid loess region of northwest China.

2. Materials and methods

2.1. Field site

The study was conducted 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 semi-arid regions (Gaolan County, Lanzhou, Gansu Province, 36°13′N, 103°47′E, elev. 1780 m above a.s.l.). Mean annual precipitation is about 263 mm with nearly 70% falling between May and September. Mean annual temperature is 8.4 °C with a maximum monthly temperature of 20.7 °C (July) and a minimum of −9.1 °C (January). Average annual pan evaporation is 1785 mm. The soil is silt loam (sand: 12.3%; silt: 66.9%; clay: 20.8%) of loess origin, which can be classified as Calciorthid (Li et al., 2006). The soil is predominantly deep (the maximum depth amounts to 300 m) and well developed, the saturated hydraulic conductivity is 19 mm h^{-1} (Li and Gong, 2002) and field water holding capacity amounts to 28% (by volume). Gravel and sand mulch is a common practice for crop production in the study area, local farmers often use pebble or sand derived from fluvial materials of the Yellow River to cover soil surface for conserving soil moisture, and a wide variety of crops have been grown in this area: melons, vegetables, fruit trees, beans, wheat, cotton and millet (Li, 2003).

2.2. Experimental design and treatments

The effect of the texture composition of gravel and sand mulch layers on runoff and soil water storage was conducted between April and October in 2003. There were four treatments with three replications: T1 = 10 cm thick pebble (4–5 cm in diameter); (2) T2 = 10 cm thick uniformly mixed pebble and sand (the grain size composition comprises: >10 mm: 43.0%; 1–10 mm: 53.0% and

Fig. 1. Concrete bordered plots (1 × 1 m) for measuring runoff and soil water content; the plot contains 10 cm thick pebbles, the black plastic sheet covering the barrel is used to prevent catching precipitation and evaporation of the collected runoff water.

<1 mm: 4.0%); (3) T3 = 10 cm thick fine sand (the grain size composition comprises: >2 mm: 9.8%; 0.05–2 mm: 87.7% and <0.05 mm: 2.5%); (4) T4 = bare soil. Twelve concrete bordered plots (1 m × 1 m) with a slope of 5° were used to measure runoff and soil water content in the open field (Fig. 1). The border of plots was 10 cm beneath and 20 cm above the surface, respectively. The soil was first leveled and then covered with mulching materials (pebbles and/or sand) from fluvial deposits of the Yellow River. PVC tube guided the runoff water from the lowest corner of the plot into a 100 L barrel, covered with a plastic sheet to prevent catching precipitation and evaporation of the collected runoff water. The runoff was measured 30 min after each rainstorm or twice daily during continuous rainfall events. A standard rain gauge and a siphon-type recording rain gauge were used to obtain the amount and intensity of rainfall. Soil moisture was measured using Time Domain Reflectometry (TDR) to a depth of 100 cm with 20 cm depth increments every month during the experimental period.

The effect of thickness of mulch layers on runoff and soil water storage was carried out between April and October in 2004. The different thickness was achieved by establishing different number of 2 cm pebble layers. There were four treatments with three replications: i.e. 1, 2 and 3-layers of pebbles and the control plots (bare soil), consequently the thickness of gravel mulches was 2 cm, 4 cm, 6 cm and 0 cm respectively, and 4 (treatments) × 3 (replicates) = 12 plots with a slope of 5° were used in this experiment. The pebbles with a 100% cover were used in the experiment. Measurements of runoff and soil water content were the same as the above paragraph described.

3. Results

3.1. Effect of the texture of gravel and sand mulch on runoff and soil water storage

Runoff response to the texture of gravel and sand mulch in 2003 is indicated in Table 1, it is clear to see that the pebble and the mixed pebble and sand mulch treatments reduced runoff substantially as compared with the fine sand and the bare soil treatments. Among the 44 rainfall events, a total runoff of 16.34 and 19.83 mm were produced from the fine sand and bare plots respectively; in contrast, a total runoff of 0.62 and 0.72 mm were