Soil and Water Accumulation by Gravel and Sand Mulches in Western Loess Plateau of Northwest China

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Abstract: The use of Gravel and sand as mulch (known as *Shatian* in Chinese) is a farming technique designed to conserve the sporadic and limited rainfall in the region of rapidly draining loess soils in Northwest China for over 300 years. However, little studies were conducted concerning the beneficial effects of gravel and sand mulches on soil and water conservation. This study showed that (1) surface gravel and sand mulch increased soil temperature, and the mixed gravel and sand mulches were more effective in improving temperature than the pure gravel or the pure sand mulch; (2) surface gravel and sand mulches were effective in suppressing evaporation and the mixed gravel and sand gravel covers tended to reduce evaporation more effectively as compared with the pure gravel or the pure sand mulch; (3) gravel or the mixed gravel and sand covers reduced runoff and increased soil moisture storage as compared with the bare soil; (4) gravel or pebble mulch could effectively control wind erosion and trap eolian dust.

Keywords: gravel mulching, soil conservation, water conservation, loess plateau, NW China

1 Introduction

Throughout agricultural history, farmers in China have developed a variety of practices to alter environmental conditions at the micro-scale to meet the physiological requirements of crops for reliable production (Gale *et al*., 1993; Nachtergaele *et al*., 1998). Gravel and sand mulching is such indigenous technology used for crop production for over 300 years in the loess area of northwest China (Wang and Sun, 1986). Gravel and sand mulched fields, known as Shatian or sandy field in Chinese, are concentrated in Gansu Province as well as adjoining counties in neighboring Ningxia Hui Autonomous Region and Qinghai Province. At present, 118,000 ha of such fields are distributed in Gansu Province. Although some researches on Shatian have revealed certain theoretical principles underlying the beneficial effects of gravel and sand mulches (Lu and Chen, 1955; Lu *et al*., 1958; Luo, 1991; Liu *et al*., 1999; Li *et al*., 2000a, b; Li *et al*., 2001a, b). However, systematic studies concerning the effects of gravel and sand mulches on soil and water conservation were scarce and lack experimental data. Therefore, a study was set up to investigate the effects of surface gravel and sand mulches on temperature, evaporation, runoff, soil moisture storage and wind erosion.

2 Materials and methods

2.1 Study site description

The field experiments were conducted at the Gaolan Research Station of Ecology and Agriculture, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. The study area is located in the west of the Loess Plateau (36º13¨N, 103º47¨E) at an altitude of approximately 1,780 m. The climate of the region is semiarid: mean annual precipitation is about 263 mm, nearly 70% falling between May and September. Mean annual temperature is 8.4℃ with a maximum temperature of 20.7℃ (July) and minimum of –9.1℃ (January). Average annual pan evaporation is

1,785.6 mm. The soil is a sandy loam of loess origin, which belongs to Haplic Orthic Aridisols (Li *et al*., 2000a).

2.2 Experimental design

Laboratory evaporation study method was similar to that described by Fairbourn (1973), plastic cylinders (30 cm long × 10 cm in diameter) were packed with air-dried loess soil passed through 2 mm sieve. There were six treatments in the experiment. With the exception of the control (bare soil surface) and the free water surface, all the treatments had a 6 cm thick gravel or sand cover overlying loess soil, namely: larger gravel (3 cm in diameter), smaller gravel (2 cm in diameter), uniformly mixed gravel and sand (0.5 cm—2 cm in diameter) and fine sand (< 0.1 cm in diameter). The gravel and sand mulches were fluvial materials of the Yellow River. Water was added at the surface in small increments until water drained from the bottom. When drainage ceased, the soil columns were placed in a constant-temperature room, (22±1)℃. Evaporation loss was determined by daily weighing the soil column. In this manner, cumulative evaporation was determined, and evaporation rates were estimated. Field studies concerning runoff and soil moisture storage were conducted at the Gaolan Research Station of Ecology and Agriculture, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences in 1999. There were four treatments with three replications: T_1 = 10 cm thick gravel (4 cm– 11 cm in diameter); (2) T_2 = 10 cm thick uniformly mixed gravel and sand (0.05 cm- 4 cm in diameter); (3) T_3 = 10 cm thick fine sand (< 0.1 cm in diameter); T_4 = bare soil surface. Twelve 3.3 by 6.0 m runoff plots with their longer sides parallel to the slope (8%) were used to 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. Runoff from each plot was collected in a 100-liter barrel, covered with a close fitting plastic sheet to prevent catching precipitation and to prevent evaporation of the collected runoff water. 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 gross rainfall. Meantime, soil moisture in the runoff plots was determined gravimetrically to a depth of 100 cm with an increment of 20 cm in August and September 1999. Soil thermometers were also installed at soil depth of 5 cm, 10 cm, 15 cm and 20 cm in runoff plots to monitor temperature variations.

The experiment of the effect of gravel on wind erosion was conducted at the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences in a push-type laboratory wind tunnel in 2001. The wind tunnel has a work section 16.2 m long, 1.0 m wide and 0.6 m high. Wind velocity can be controlled continuously from 0.5 $m \cdot s^{-1}$ to 35 $m \cdot s^{-1}$. The sample tray was placed on an electronic balance mounted on the floor of the working section, 12 m from the entry of the test section of the wind tunnel (Chen *et al*., 1996, Li *et al*., 2001b). The surface of the sample was set level with the floor of the tunnel. There were five treatments, i.e. four cover densities of 0, 25, 50, 75 and 100 per cent using 5 cm thick pebbles 5.0 cm in diameter and the bare soil (0% cover density). Wind velocity was measured with a pitot tube installed parallel to the central axis of the wind tunnel and 20 cm above the sample surface. Three erosive wind velocities 10 $m \cdot s^{-1}$, 18 $m \cdot s^{-1}$ and 26 $m \cdot s^{-1}$ were applied in the experiment and the test time is 15 min, 4 min and 2 min. respectively. Soil loss during each test was measured by the electronic balance as the weight difference before and after a test. Weight loss in gram was converted to erosion modulus ($g \cdot m^{-2} \cdot min^{-1}$) to signify the wind erosion rate. The eroded soil was also collected with step-like silt passive sampler to calibrate soil loss (Chen *et al*., 1996). The experiment of dust accumulation by pebble mulch was conducted at the Gaolan Research Station of Ecology and Agriculture, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. Fifteen 1 m × 1 m plots with 15 cm high cement block borders were established to measure dust accumulation in the open field. Four cover densities using pebbles 5.0 cm in diameter were simulated with the point-grid method: i.e. 25, 50, 75 and 100 per cent. There were three replicates for each treatment. Three plots only covered with 1.2 mm thick black plastic film were considered as controls. The remaining 12 plots were first covered with 1.2 mm thick plastic film, then about a 10 cm-thick layer of washed pebbles with different densities were spread on the plastic film in the corresponding different plots. The plots were installed on 10 December 2000 and remained outside until 10 May 2001. Dust accumulation was thus measured for a period of 5 months. The deposited windblown materials in the plots were collected with a brush after pebble removal. Silt and clay adhering to the surfaces of pebbles and plastic film were obtained by washing and drying. The total amount of trapped windblown sediments was determined with a 1/100 A/D electronic balance. Dust accumulation was expressed as windblown material amount on per unit area per day (g • m^{-2} • d^{-1}).

3 Results and discussions

3.1 Soil temperature

Measurements of the soil temperature indicated that there was a systematic temperature increase due to gravel and sand mulches. Soil temperature under gravel and sand covers was 0.5℃-4℃ higher than the bare soil. This was consistent with Lamb and Chapman (1943) and Fairborn (1973) findings, indicating that the presence of non-porous rock fragments increase thermal diffusivity (i.e., the ratio of thermal conductivity to heat capacity). Meantime, it was interesting to note that mixed gravel and sand mulches were more effective in improving temperature than the pure gravel or pure sand mulch, namely about 2℃ higher under the mixed gravel and sand mulches than under the pure gravel or pure sand mulch (Fig. 1). Favorable soil temperature conditions due to gravel and sand mulches help to hasten germination and emergence of crop as well as early harvest.

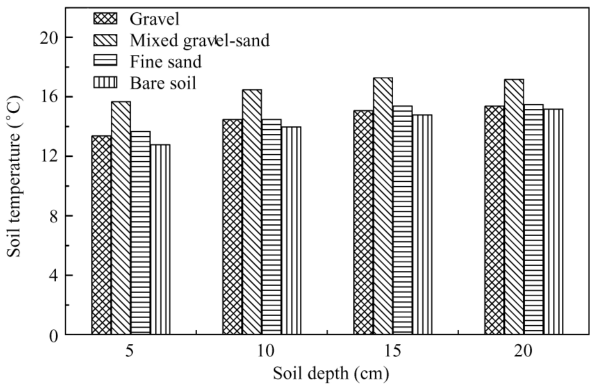

Fig. 1 Soil temperature comparison for gravel and sand mulches on 10 May 1999

3.2 Evaporation control

The effect of gravel and sand mulches on evaporation is indicated in Fig. 2. In this Fig., three

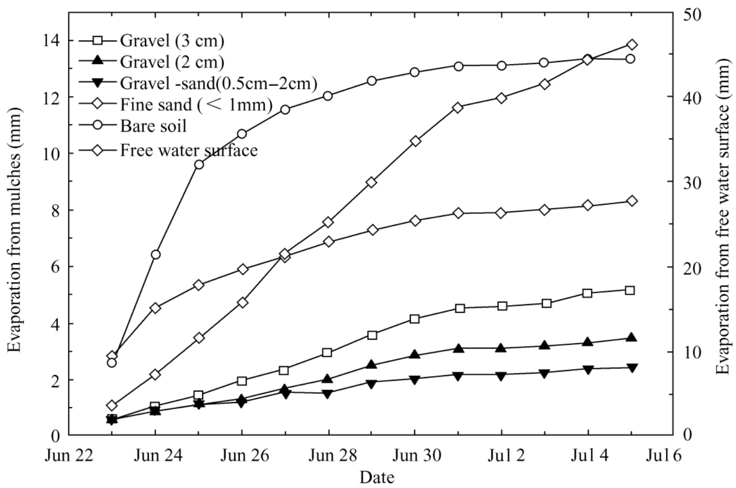

Fig. 2 Cumulative evaporation with time for gravel and sand mulches

stages of evaporation can be distinguished. The first stage includes the rapid and somewhat constant rates of water loss over the first 3 d (23 June – 25 June). The second stage involves the decrease in evaporation rate, presumably due to surface drying, over the next 6 d (27 June – 1 July). The third stage occurs after about 9th day when evaporation rates are slow but relatively constant (2 July – 5 July). After 14-d experiment, the cumulative evaporation for the bare soil was 13.33 mm, followed by fine sand (8.3 mm), lager gravel (5.2 mm), smaller gravel (3.5 mm) and mixed gravel and sand (2.4 mm). This demonstrates that gravel and sand mulches are effective in suppressing evaporation. Moreover, mixed gravel and sand gravel covers tend to reduce evaporation more effectively as compared with pure gravel or pure sand mulch.

3.3 Runoff and soil moisture content

Runoff behavior was significant different in the gravel-mulched plots and sand-mulched plots in this experiment. Pure gravel and mixed gravel and sand reduced runoff substantially as compared to pure sand and bare soil (Fig. 3). Among the 44 rainfall events, a total runoff of 19.83 mm and 16.33 mm were produced from fine sand and bare plots respectively; in contrast, a total runoff of 0.6 mm and 0.7 mm runoff were produced from the gravel and mixed gravel-sand plots respectively. The high runoff amount from fine sand plots might result from high clay content, which is easy to form a surface seal (Li and Gong, 2002). The results suggest that surface gravel or gravel-sand mulches was more effective in retaining runoff as compared with sand mulch.

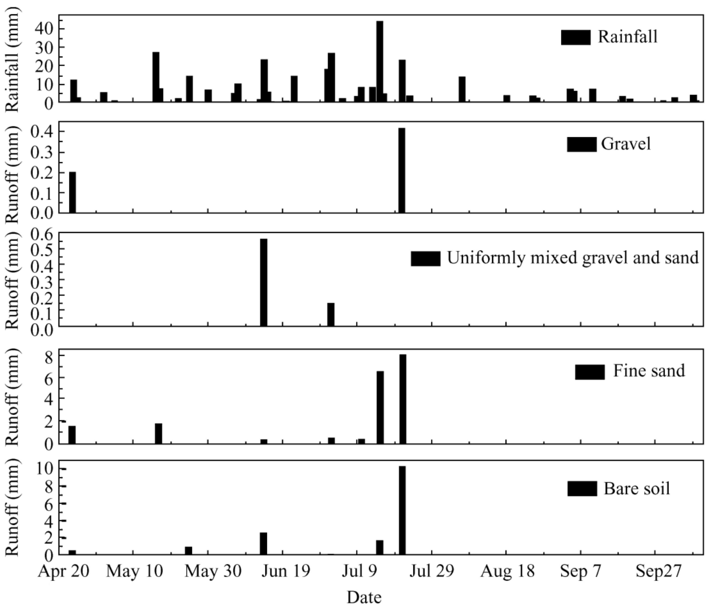

Fig. 3 Daily rainfall and runoff distributions for gravel and sand mulches during the year of 1999

The effects of gravel and sand mulches on soil moisture distribution are presented in Fig. 4. It is apparent that water content is higher for gravel and sand treatments than the bare soil at soil depth from 0 cm to 60 cm. Moreover, mixed gravel and sand covers tend to conserve more water than other treatments, and this corresponds well with evaporation and runoff characteristics mentioned above.

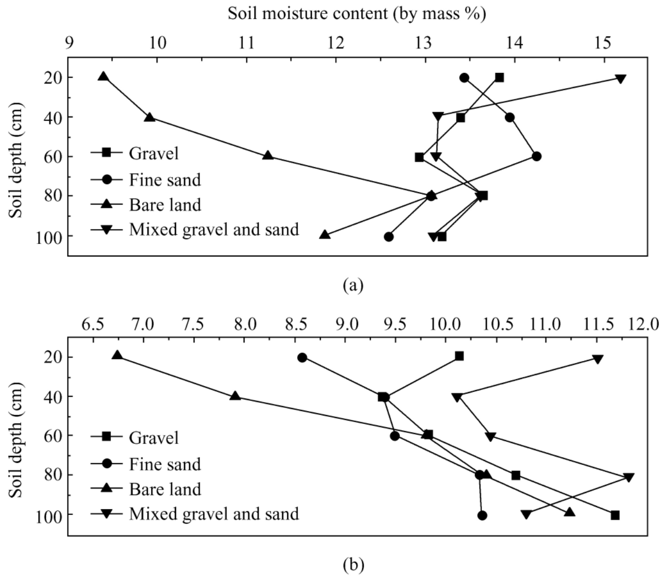

Fig. 4 Moisture content (by mass) versus soil depth for gravel and sand mulches and bare treatments in August (a) and September (b) 1999

3.4 Wind erosion and dust accumulation

Gravel on the soil surface influence surface roughness, and hence the vertical velocity profile of the wind and the structure of the air flow. Goossens (1994) concluded that, over stony surfaces, aerodynamic roughness length was higher than over stone-free surfaces, but the vertical wind velocity gradient close to the ground was lower. This means that stone covers can increase the degree of turbulence of the air stream and deflation threshold, and therefore the underlying surface is well protected.

Figure 5 indicates that wind erosion rate constantly decreases with increasing pebble cover densities following a negative exponential function at the wind velocities of 10 m • s^{-1}, 18 m • s^{-1} and 26 m • s^{-1}, suggesting that gravel mulch is effective in controlling wind erosion. In contrast, dust accumulation increases with increasing cover densities, following a positive exponential function (Fig. 6). It is obvious that dust accumulation contributes major suppliers of nutrient to the pebble-mulched fields, which might be one factor responsible for maintaining soil fertility (Li, 2002). The results are consistent with study conducted by Li *et al.* (2001b), which indicted that gravel or pebble mulch had two functions in controlling wind erosion: first, it can prevent soil from being eroded by wind; second, it can trap windblown dust.

4 Conclusions

The main results of the study can be summarized as follows:

(1) Surface gravel and sand mulch increased soil temperature, and mixed gravel and sand mulches were more effective in improving temperature than pure gravel or pure sand mulch.

(2) Surface gravel sand mulches were effective in suppressing evaporation. Moreover, mixed gravel and sand gravel covers tended to reduce evaporation more effectively as compared with pure gravel or pure sand mulch.

(3) Gravel or mixed gravel and sand covers reduced runoff and increased soil moisture storage as compared with the bare soil.

(4) Gravel or pebble mulches can effectively control wind erosion and trap eolian dust.

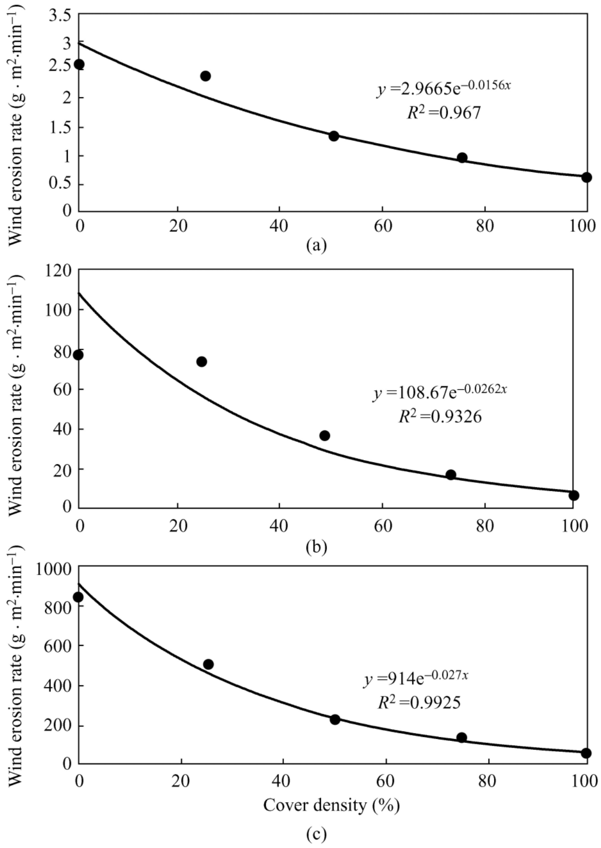

Fig. 5 Relationship between wind erosion rate and pebble cover density at different wind velocities; a: 10 m • s^{-1}; b: 18 m • s^{-1}; c: 26 m • s^{-1}

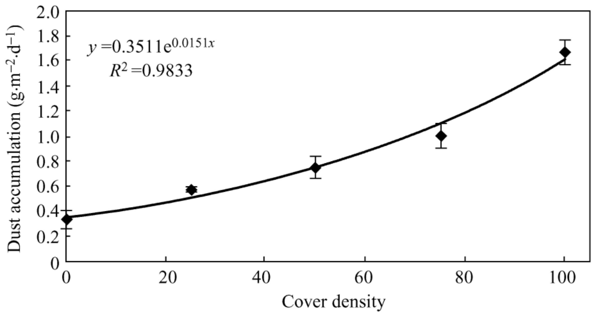

Fig. 6 Dust accumulation by pebble mulch for different cover densities

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