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Effectiveness of geotextile mulches for slope restoration in semi-arid northern China

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ABSTRACT

In semiarid areas, slope restoration is usually hampered by high rainfall and temperature variability. These may cause severe erosion and slope instability, also environmental stresses, such as long-term drought and temperature extremes that lead to revegetation failure. In this study, three types of geotextiles including jute mat (JM), polyester mat (PM) and polyester net (PN) were installed on slopes and their effects on erosion control and vegetation growth were investigated by both laboratory and field experiments. The results of rainfall simulation experiments on laboratory plots showed that JM, PM and PN could delay the time to runoff, reducing runoff by 62.1%, 57.7% and 16.6%, and decrease erosion by 99.4%, 98.5% and 5.5%, respectively. Field studies were also conducted on a restored rock slope in Fengshan quarry, northeast Beijing, China, in both 2010 and 2011. Results indicated that JM, PM and PN could increase soil moisture by 54.5%, 36.3% and 18.7%, respectively, and provide more moderate soil temperatures that facilitate vegetation growth. The geotextiles were less effective in 2011 than in 2010 as a result of their degradation over time. Slope stability and plant growth, however, were not affected due to the developed vegetation cover. Thus geotextiles could protect slopes by preventing erosion and creating favourable soil conditions for revegetation, especially in the initial stage of slope restoration, and the natural geotextile mat (jute mat) is preferred since it is more effective and more environmental friendly.

1. Introduction

Along with the construction of infrastructure including roads, railways and pipelines, and the exploitations of quarries and mines, abundant bare steep slopes have been created. They have the potential to cause severe environmental impacts, such as the visible disturbance of landscapes, the removal of natural soil and vegetation, and the increased erosion and landslides. Therefore many attempts have been made to stabilise and restore these damaged slopes by using various techniques, among which biotechnical methods for revegetation, such as hydroseeding (Albaladejo Montoro et al., 2000), are becoming more popular mainly because of their environmental benefits and economic advantages. Vegetation is highly effective in protecting slopes since it is able to reduce runoff and erosion by intercepting rainfall, reducing flow velocity and encouraging infiltration, and stabilize the soil with root systems (Coppin and Richards, 1990; Sanchez and Puigdefabregas, 1994).

However, in semiarid environments, the establishment of vegetative cover on bare slopes is especially challenging as it is often limited by high rainfall and temperature variability (Bochet and García-Fayos, 2004). For example, in semiarid northern China, rainfall during winter and spring (from November to April) accounts for less than 20% of annual rainfall, not only characterized by high rainfall intensity that may cause severe soil erosion, but also by low reliability that may lead to long periods of drought. The high evaporation by strong winds in these seasons also determines low soil moisture and unfavourable conditions for plant germination and growth. Moreover, the soil layer established on steep slopes is usually very thin and highly compacted to ensure its stability, further leading to an intense water deficit. These factors cause high rates of plant mortality because of low infiltration and high runoff (Cano et al., 2002). In addition to the drought, another risk at early plant growth stages is the instability of surface soil layer caused by intense rainfall, which usually happens in semiarid areas. Vegetation can only be effective in protecting slopes after a closed canopy is developed, and the critical stage between germination or planting and full maturity represents a window of high erosion risk (Rickson, 2006). Seeds or seedlings could be damaged or even washed away by large volumes of runoff, which in turn makes vegetation establishment extremely difficult. Besides, the temperature stress with high temperature variations and high temperature extremes is another limiting factor in semiarid environment for plant establishment on slopes (Beikircher et al., 2010).

In order to prevent environmental stress on plant growth and reduce erosion risk at the early stages of revegetation, mulching methods were selected in this study, due to their potential for creating

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favourable conditions for plant growth and erosion control (Brofas and Varelides, 2000) by shielding the soil and seeds from the impact of rain and wind. Geotextiles, which have been widely applied in civil engineering to strengthen the soil structures (Methacanon et al., 2010), can be used as the mulching materials. Geotextiles are defined as 'permeable textiles used in conjunction with soil, foundation, rock, earth or any geotechnical engineering related material, as an integral part of a man made project' (John, 1987). They can be made from either synthetic (polypropylene, polyester, polyethylene, polyamide, etc.) or natural fibres (jute, coir, sisal, cereal straw, palm-leaf, etc.) with different designs, shapes, sizes, and composition according to functional needs (Rickson, 2006). Previous research has highlighted the positive effect of geotextiles on soil erosion control. For instance, the effectiveness of palm-mats on reducing soil erosion was demonstrated by Bhattacharyya et al. (2008) through experiments conducted on 1 m × 1 m soil plots. Jankauskas et al. (2008) also found that geotextile mats made of natural fibres were an effective and sustainable soil conservation technique for roadside slopes. However, the effects of geotextiles on slope restoration, especially their effects on soil conditions and vegetation growth in semiarid areas have been seldom studied. In addition, most studies considered only one type of geotextile, but little work has been done to compare the effects of different geotextiles.

Therefore, three types of geotextile (jute mat, polyester mat and polyester net), representing geotextiles made from different materials (synthetic and natural fibres) and in different forms (mat or net), were tested in this study. The objectives were: (1) to assess the erosion-reducing potential of the three types of geotextile through õlaboratory experiments under simulated rainfall; (2) to investigate geotextile performance in improving soil environment (i.e., moisture and temperature) and vegetation growth through field studies; (3) to compare geotextile effectiveness over time. The results of this study were expected to help improve slope ecological restoration practice in semi-arid areas.

2. Material and methods

2.1. Geotextiles

Three types of geotextiles were used in this study. The first one was jute mat (JM) made from woven natural jute fibre. It was 20 mm thick and 500 g/m^2 with three layers: a jute net layer (1 cm^2 aperture size) on the top for enhancing the tensile strength of the whole structure, a nonwoven layer at the bottom acting as a supporting base, and a jute fibre layer (80% porosity) filled between them (Fig. 1a). Since the nonwoven bottom layer was very thin (only 1 mm thickness) and would become very soft when was wetted by the rain, the vegetation was able to penetrate through it. Also due to its high degradation rate (usually in 90 days) in the field, it would not impede the plant emergence and growth.

Another type of geotextile mat, the polyester mat (PM), was made from synthetic polyester fibre. It had a similar multiple-layer structure as JM, however with different materials and features: the top layer was a polyester net that had an aperture size of 0.25 cm^2, the middle layer was polyester fibre that had a porosity of 90%, and the bottom nonwoven layer was the same as that of JM (Fig. 1b). These three layers resulted in an entire thickness of 15 mm and a mass per unit area of 400 g/m^2.

In addition to the two geotextile mats, a geotextile net namely polyester net (PN) was also used in this study. It had only a single polyester net layer which was the same as the top layer of PM (Fig. 1c), leading to a small thickness (2 mm) and a large open area percentage (70%).

2.2. Laboratory experiment

Laboratory experiments were conducted in the rainfall simulation laboratory of Beijing Normal University, to investigate the surface runoff and soil erosion. Plots were prepared by spraying the substrate, consisting of a mixture of soil (70%), compost (25%), fertilizer (4%), water retaining agent (0.5%) and soil adhesive (0.5%), onto the platform (2 m × 1 m, 40°) by hydroseeding to form a substrate layer with a thickness of 20 cm. This type of substrate is commonly used in the slope restoration practice in semi-arid northern China. The water retaining agent and soil adhesive were added to improve the water holding capacity and the stability of the constructed substrate layer on the steep slopes. Then four treatments were set up: three types of geotextiles and a control bare plot (CP) (Fig. 2). Simulated rainfall was produced by a group of rainfall simulators which use Veejet 80100 nozzles, with water pressure of 0.04 MPa, height of 5 m, target area of 2.2 m × 3 m, and 95% coefficient of uniformity. Three intensities of rainfall (10 mm/h, 30 mm/h and 50 mm/h) were each applied for 1 h on all the plots. The soil moisture in each plot was monitored by setting up two soil moisture meters at 5 cm depth. Before each rainfall event, the initial moisture of substrate was always controlled as around 10% to make the starting conditions constant. In a rainfall event runoff start time (min) was recorded, runoff was collected at the outlet using buckets and total runoff volume (L) was measured. After the rainfall event sediment concentration (g/L) of the runoff was determined by oven-drying five collected runoff samples at 105 °C for 48 h, and total sediment load (g) were calculated by multiplying the mean sediment concentration by total runoff volume. For the replication purpose, the above processes were precisely repeated three times by reconstructing the plots, re-setting the treatments and re-applying the simulated rainfall using the same methods, materials and procedure introduced above. This resulted three replicates for each treatment and also three replicates for each rainfall event.

2.3. Field study

A field study was carried out on a restored rock slope in Fengshan quarry, northeast Beijing, China, to investigate and monitor substrate conditions and vegetation growth. This slope, located at N39°53′32″, E121°38′29.1″, is in a semiarid climatic region, where annual mean temperature is 11.8 °C and annual mean rainfall is 550.3 mm. The slope is approximately 60 m long and 40 m wide, facing south, with a mean gradient of 50° (ranged from 30° to 70°). The original natural soil and vegetation were totally removed by quarrying, resulting in a rough slope of moderately weathered bare rocks (Fig. 3).

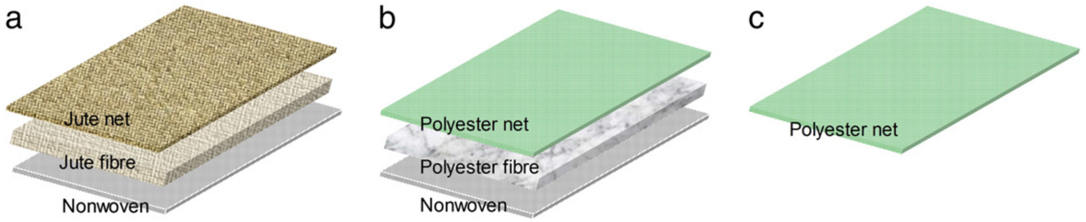

Fig. 1. Schematic diagram of geotextiles: (a) jute mat (JM); (b) polyester mat (PM); (c) polyester net (PN).