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Effects of different backfill soils on artificial soil quality for cut slope revegetation: Soil structure, soil erosion, moisture retention and soil C stock

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ABSTRACT

Large-scale railway/highway construction in hilly areas in China has created a number of bare rock cut slopes. Artificial soil is often sprayed onto those slopes to promote revegetation. The artificial soil used is a mixture of backfill soil, humus, straws, soluble chemical fertilizer, composite material and plant seeds. The backfill soil is the most important component of the artificial soil. Knowledge of the changes in the artificial soil quality induced by backfill soil is important for the management of the revegetation of rock cut slopes. This study was conducted to assess the effects of different backfill soils on soil quality parameters and slope restoration parameters, including the particle size distribution, water-stable aggregates, soil organic carbon (SOC), organic carbon fractions, soil water characteristics (SWC), plant coverage, Margalef index and Shannon–Wiener diversity index. In experiment one, the treatments included slopes backfilled with rock fragment (RF), slopes backfilled with agricultural soil (AS) and a natural slope (NS). In experiment two, the treatments were experiment plots with different proportions of agricultural soil to rock fragments. Soils were sampled from the surface layer (0–5 cm) of the slopes. The results indicated that the backfill soil significantly affected the soil structure. RF increased the percentage of large particles (>0.25 mm) and decreased that of micro-particles (<0.25 mm). The fractal dimension and the water-stable aggregate content of RF were smaller than those of AS. Moreover, RF exhibited the highest soil destruction rate of soil aggregates among the three treatments. Our findings also indicate that RF conserved a smaller percentage of SOC in less degraded forms (coarse and fine particulate organic matter (POM) fractions) than AS management. At almost all of the soil suctions studied, AS retained more volumetric water content (θv) than RF or NS. The AS soil contained 17.3% more plant available water (PAW) than the RF soil. The plant coverage, Margalef index and Shannon–Winner were investigated to evaluate the restoration of the rock cut slopes compared with natural slopes. The three parameters of the RF were all smaller than those of the AS and NS. Overall, RF exhibited poorer soil structure and hydrological properties, increasing the risk of surface runoff and soil erosion because it had not undergone sufficient soil-forming processes and lacked SOC. Therefore, the use of rock fragments as backfill soil was not helpful for maintaining artificial soil with sufficiently high quality for the slope revegetation.

1. Introduction

Large-scale railway/highway construction in hilly areas of China has created a number of bare rock cut slopes. The protection of rock cut slopes is of great importance for local railway/highway safety and ecological conservation. Hydroseeding, which involves spraying artificial soils onto the surface of the slopes to promote revegetation, is widely used to remediate such rock cut slopes in China. The hydroseeding technology includes five steps: (1) preparation of artificial soil, (2) setting rock bolts, (3) laying protective webs, (4) spraying artificial soil, (5) laying non wovens (Fig. 1). The artificial soil used is a mixture of backfill soil, humus, plant fibers, soluble

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Fig. 1. The steps of hydroseeding technology.

chemical fertilizer, composite material and plant seeds. There are two types of backfill soil. One is rock fragments obtained from the cut slope surface after crushing and passing through a 2 mm sieve. The other is agricultural soil obtained from the farmland nearby after crushing and passing through a 8 mm sieve. In recent years, more and more rock fragments have begun to be used as backfill soil to replace agricultural soil by restoration practitioners (Ai et al., 2012). However, the structure failure of soils sprayed on the slopes is serious, and the established vegetation usually degrades with 2–3 years (Feng, 2007; Liu and Han, 2007; Zhao, 2012). The backfill soil is an important component of the artificial soil used to cover the slope surface, which supplies the vegetation with root anchorage and a nutrient source. The rock fragments used as backfill soil have not undergone adequate soil-forming processes. Thus, it is important to determine whether these changes in the backfill soil contribute to the degradation of the artificial soil and the established vegetation.

Previous research on this technique has focused on (1) screening proper slope-protection plants and optimizing their combination (Karim and Mallik, 2008; Tormo et al., 2008; Beikircher et al., 2010), (2) the vegetation outcomes in terms of ecology, botany and climate (Martínez-Ruiz et al., 2007; Bhattarai et al., 2008; González-Alday et al., 2008; Alday et al., 2010; García-Palacios et al., 2010), (3) optimizing the component ratios of artificial soils (Gao et al., 2007) and describing the influential factors for revegetation (Alday et al., 2010; Ai et al., 2012), and (4) the stability and erosion resistance of cut slope protection from the perspective of geotechnical engineering (Lee et al., 2007). However, the validity of the rock fragments as backfill soil has not been evaluated.

The maintenance of a suitable soil structure is essential for maintaining soil with sufficiently high quality for revegetation (Daynes et al., 2013). The management of soil structure is essential for optimizing the particle size distribution, porosity and aggregate stability (Blanco-Canqui et al., 2005; Abid and Lal, 2009; Pastorelli et al., 2013; Abdollahi et al., 2014). Thus, it is essential to adopt management strategies that maintain and/or improve the soil physical quality and alleviate specific soil-related constraints (Shukla et al., 2003; Abid and Lal, 2009).

Knowledge of the water and soil organic C (SOC) retention properties of the soil will aid the maintenance of soil quality and sustainable revegetation. Measurements of the soil water retention (SWR) capability are essential for estimating the soil water characteristic (SWC) and plant available water (PAW). SOC is the most important soil parameter and strongly affects the soil structure and growth of plants (Muhammad et al., 2014). Its quantity and quality can be modified by management practices (Shreyasi et al., 2014). Previous research (Paul, 2004; Mikha et al., 2012) has reported that the evaluation of SOC pools can better reflect the changes in total SOC and soil aggregate dynamics. The particulate organic matter (POM) was found to be the most easily measurable C pool, and changes in its magnitude were common (Oorts et al., 2007; Mikha et al., 2012). When POM decomposes and breaks down to $<53\,\mu m$, the POM becomes physically and/or chemically stabilized within the soil mineral components as mineral-associated organic matter (MAOM) (Lützow et al., 2006; Rumpel and Kögel-Knabner, 2011; Mikha et al., 2012). Mineral-associated organic matter carbon (MAOM-C) has been reported to be the recalcitrant form of C because this C becomes inaccessible to microbial decomposition (Lützow et al., 2006; Rumpel and Kögel-Knabner, 2011). Therefore, SOC distribution in POM-C and MAOM-C is often used to evaluate soil C protection and stabilization.

Our goal was to evaluate the effects of different backfill soils on the artificial soil quality for cut slope revegetation. Based on the results, the validity of the use of rock fragments as backfill soil was determined. We hypothesized that: (1) the use of rock fragments as backfill soil in the rock slope revegetation leads to poorer soil structure and hydrological properties, increasing the risk of surface runoff and soil erosion of the slopes, (2) the use of rock fragments as backfill soil for cut slope revegetation limits the soil C stock and the establishment of the vegetation, in terms of vegetation cover and species richness of the slopes.

2. Materials and methods

2.1. Study site and treatment description

The study site is located near Suining Railway Station on the Suining-Chongqing line, Suining, Sichuan Province, China