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Research article

Vegetation and soil nutrient restoration of cut slopes using outside soil spray seeding in the plateau region of southwestern China

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ABSTRACT

Outside soil spray seeding (OSSS) is used widely for road cut revegetation, and the artificial soil used in OSSS can improve slope soil conditions and nutrients, and help promote plant growth and succession. Three different slopes was investigated to evaluate the effectiveness of OSSS for restoration, including a natural slope (NS), a cut slope without any artificial recovery treatment (CSW) and a cut slope treated with OSSS (CSO). The recovery of cut slopes was determined by evaluating a number of factors, including indices associated with plants on the slopes, soil enzyme activities (urease and sucrase), and soil nutrient content (soil organic matter (SOM), total phosphorous (TP), total potassium (TK), available nitrogen (AN), available phosphorous (AP), available potassium (AK), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and sulphate (SO_4^{2-})). The results indicated that the vegetation and soil conditions differed between the three slopes. The Shannon-Wiener index (H), the Simpson index (D), and the Margalef index (R) values from the CSO and NS were lower than those of the CSW, whilst the Pielou index (E) value and vegetation canopy cover were higher for the CSO and NS than for the CSW. The content of SOM and AN in soil from the CSO was lower than in soil from the NS and CSW, and content of many nutrients were higher in soil from the CSO than in soil from the NS and CSW. This suggests that the restoration of vegetation and soil nutrients on the CSO was relatively successful. Our results indicated that the use of OSSS to restore cut slopes is effective in plateau areas. However, despite improvements in soil nutrient levels, there were still nutritional imbalances. Therefore, more attention should be paid to balancing nutrients in the later stage of OSSS implementation for the recovery of cut slopes at high altitudes.

1. Introduction

The rapid development of the Chinese economy in recent years has resulted in the construction of many roads (Singh et al., 2014). This has led to the creation of many cut slopes, which can cause environmental damage, including soil erosion, rock exposure, habitat destruction, landslides, as well as other hazards (Xiao et al., 2015). These effects on the environment can pose serious dangers to transportation (Bochet and García-Fayos, 2004; Chirico et al., 2013), particularly in the southwest region of China, where the plateau terrain is particularly rugged (Zhang et al., 2018). Southwest China includes many high altitude areas, which are characterised by long sunshine hours, very cold temperatures, a changeable climate, and concentrated rainfall, and as such, these areas are more prone to landslides, debris flow, and other natural disasters. Therefore, reconstruction of embankment slopes and vegetation recovery must be carried out after road construction to enhance the stability of cut slopes, prevent and control soil erosion, and beautify the highway (J.Gong et al., 2007; Chen et al., 2015). Outside soil spray seeding (OSSS) is commonly used to artificially restore cut slopes in the southwest plateau region of China (Liao and Rao, 2013). This process involves three steps: modification of the mountain environment; introduction of protection nets; and the spraying of artificial soil. This artificial soil typically consists of a mixture of soil, humus, fertiliser, stabilizing agent, and seeds (see Table 1 for details of the mixing materials and proportions). The seeds used in OSSS usually include Italian ryegrass (*Lolium perenne* L.) and alfalfa (*Medicago sativa* L.). However, the growing period of Italian ryegrass only encompasses approximately four months of the earlier engineering stage (Gao et al., 2016).

Artificial soil is an important part of engineering the slope stability of steep rock slopes, and is often sprayed on slopes to promote restoration of vegetation, where it serves to create the necessary conditions for the growth of plants (Xu, 2008; Chen et al., 2014; Chen et al.,

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Table 1
Mixing materials sprayed onto slopes.

Mixing materials Proportions	Proportions
Humus	6.25 kg/m^2
Straw	0.1 kg/m^2
Soluble chemical fertiliser	(N: P_2O_5:K_2O = 16: 6: 8) 0.3 kg/m^2
Composite material (bonding and water-retention agents)	0.225 kg/m^2
Commercial seed mixture (*Lolium perenne* L. and *Medicago sativa* L.)	0.03 kg/m^2
Backfill soil (rock fragments and agricultural soil)	

2018). Although the use of soil, fertiliser, and stabilizing agent is known to provide favourable conditions for cut slopes in the early recovery stage, there is little knowledge on the effect of vegetation restoration and soil nutrient content during the later stages of the OSSS process. Previous research regarding the properties of cut slopes in southwest China have mainly focused on the use of artificial soil substrates (Xu et al., 2017; Zhao et al., 2018a,b) and improvements to artificial soil particle composition (Gao et al., 2016). However, very few studies have focused on restoring vegetation and soil nutrients on cut slopes in plateau regions, even though previous studies have shown that vegetation plays a decisive role in preventing landslides and controlling soil erosion (Gyasiagyei, 2004; Fan and Lai, 2014). Plant diversity exerts an important influence on the slope ecosystem and its soil properties (Gould et al., 2016), where the presence of plants directly influences the distribution of soil nutrients and the efficiency of slope recovery (Tian et al., 2017). This is because decomposition products from plants over many generations affect soil nutrient input and microbial growth/activity, thus directly influencing the carbon and nitrogen cycle of the soil (Tobyd and Johnm, 2008). Plant litter can also improve soil fertility by promoting the activities of soil animals and microorganisms, and the

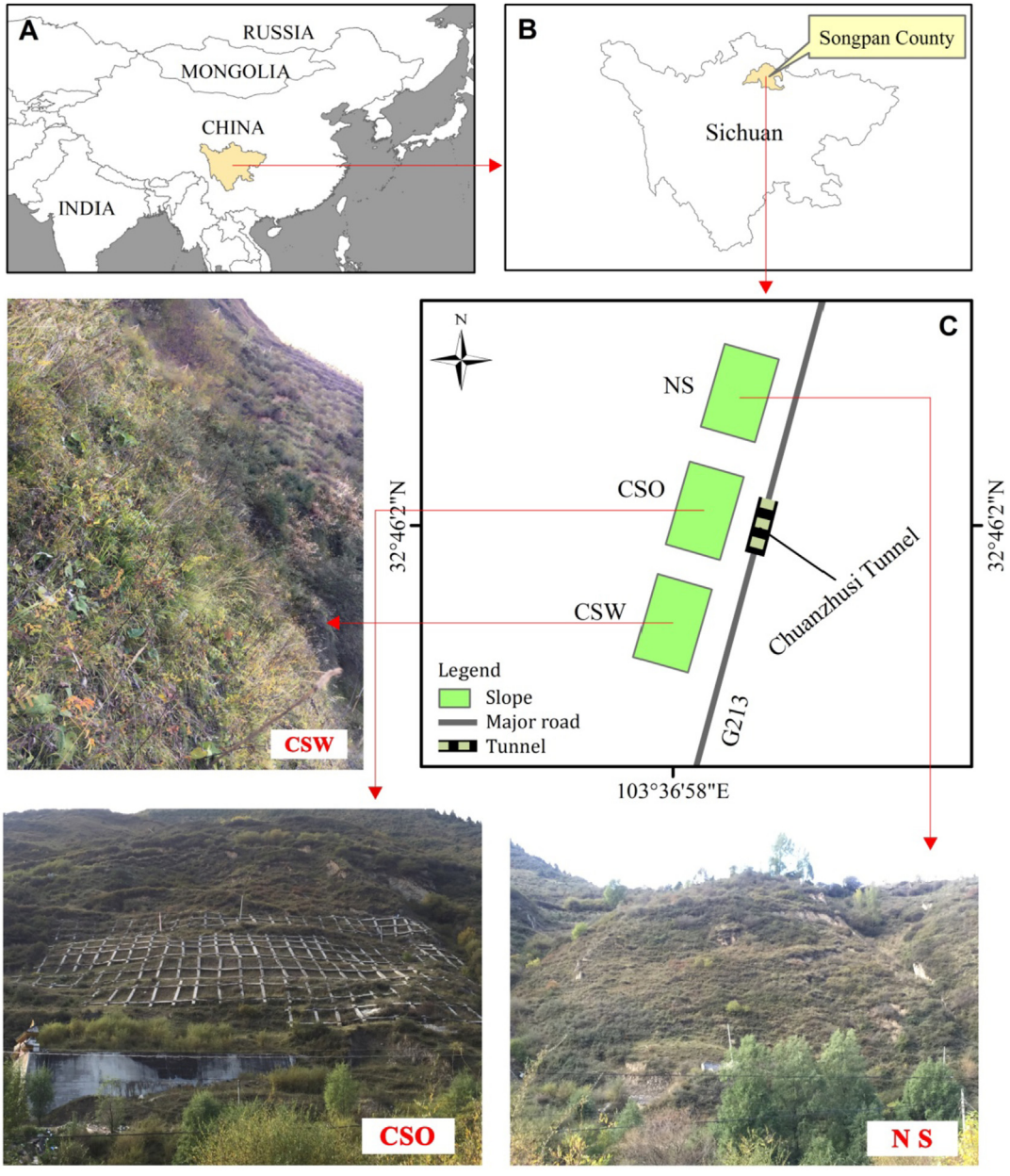

Fig. 1. Location of the study area and distribution of the sample sites. NS: Natural slope; CSW: the cut slope without any artificial recovery; CSO: the cut slope with OSSS.