Soil & Tillage Research 184 (2018) 11–23

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Effect of different vegetation restoration types on fundamental parameters, structural characteristics and the soil quality index of artificial soil

Ruirui Li[a], Shasha Kan[b], Mengke Zhu[a], Jiao Chen[a], Xiaoyan Ai[c], Zhaoqiong Chen[d], Jianjing Zhang[e], Yingwei Ai[a,*]

[a] Key Laboratory of Bio-resources and Eco-environment (Ministry of Education), College of Life Sciences, Sichuan University, Chengdu 610064, China
[b] Key Laboratory of Freshwater Fish Reproduction and Development (Ministry of Education), College of Life Sciences, Southwest University, Chongqing 400700, China
[c] College of Life Sciences, Sichuan Normal University, Chengdu 610066, China
[d] Chengdu Medical College, Chengdu 610500, China
[e] Department of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China

ARTICLE INFO

Keywords:
Vegetation restoration type
Artificial soil
Soil quality index

ABSTRACT

Outside soil spray seeding (OSSS), the technology of spraying an artificial soil mixture onto the surface of cut slopes for creating a bed for plant species to germinate and grow, has been widely used to restore cut slopes. The vegetation cover can effectively resist soil erosion, improve soil quality and facilitate the ecological restoration of cut slopes. However, researchers have different views on what kind of vegetation cover is best to improve artificial soil quality and enhance the structural stability of cut slopes. To evaluate the effect of different vegetation restoration types on the artificial soil of cut slopes restored with OSSS, various soil samples were obtained from four treatments [herbaceous-only vegetation restoration slopes (HS); mixed vegetation restoration type slope I, composed of herbs and shrubs (MSI); mixed vegetation restoration type slope II, composed of herbs, shrubs and trees (MSII); and natural slopes (NS)]. Three slopes were selected for HS, MSI, MSII and NS, respectively, for a total of twelve slopes. The soil properties measured included some fundamental parameters (physical, chemical and biological parameters) and structural characteristics (bias coefficients, peak convex coefficient, fractal dimension, structural failure rate and soil erodibility). Principal component analysis (PCA) and ascending and descending functions were used to determine an integrated soil quality index (SQI). The results showed that there are significant differences in fundamental parameters, structural characteristics and the SQI between HS and other treatments, while the same properties, except SQI, were not significantly different between MSI and MSII. These findings imply that the HS is not suitable for long-term restoration on cut slopes, whereas MSII is a better vegetation construction model for the ecological restoration of cut slopes. However, there is still a huge disparity in these soil properties between the cut slopes and NS; this difference is attributable to the NS having a soil optimization process with long-term no human interference. Therefore, more effective management measures should be implemented to promote the ecological restoration of cut slopes.

1. Introduction

The construction of highways, railways, pipelines, and mines lead directly to the formation of a large number of steep and bare cut slopes (Shao et al., 2014). Consequently, the original topsoil and vegetation environment are destroyed, resulting in soil and water loss, landslides, soil degradation, and rock displacement along with other ecological and environmental problems (Lee et al., 2013). Road landslides have become widespread catastrophic accidents in China. Southwestern China, particularly, is a mountainous region, which generates numerous cut slopes because of traffic construction. Thus, the potential risks are also large. According to the statistics, in 2008, about 39.8% of the total length (4243 km) of key trunk roads in Sichuan Province was prone to accidents as some of the sections had disastrous events, which caused a direct economic loss of more than 58 billion Yuan (Chen et al., 2015a). Therefore, improving the safety of bare cut slopes along the railway/road lines has become an urgent task.

Many methods have been used to restore cut slopes in most areas including vegetation, pre-stressed rock anchors with vegetation, green coating, stone masonry and gabions, grille beam, and one row of piles. Among these, vegetation is an effective, environmental-friendly approach for slope engineering (Stokes et al., 2014). Shao et al. (2014)

* Corresponding author.
E-mail address: aiyw99@sohu.com (Y. Ai).

https://doi.org/10.1016/j.still.2018.06.010
Received 31 July 2017; Received in revised form 14 June 2018; Accepted 28 June 2018

determined that plant root systems can resist soil erosion, intercept rainwater, reduce water flow rate and weaken penetration. Consistent with this, some researchers have demonstrated that plant root systems have an important effect on improving slope soil quality (Yang et al., 2016; Chau and Chu, 2017) and enhancing resistance to soil erosion (Fattet et al., 2011). Moreover, soil organic matter, soil structure, soil nutrient cycling, and microbial community dynamics are considerably improved by increasing soil surface litter (Angst et al., 2017), and then, soil water holding capacity will also be increased due to the increase of soil organic matter. However, it is difficult to establish vegetation cover on the bare cut slopes through natural succession processes within a timely manner, thus some artificial restoration methods are often used to restore these cut slopes (Chen et al., 2016). A common approach for ecological restoration is outside soil spray seeding (OSSS), which involves the fixing of a protective net on the bare cut slopes, and the spraying of artificial soil mixture to the disturbed areas using a sowing machine (Fang et al., 2014; Huang et al., 2017). This is an effective and eco-friendly approach based on the following steps (Chen et al., 2015b): (1) mixing artificial soil and plant seeds; (2) installing rivets and fixing piles; (3) covering with protective net (barbed wire); and (4) spraying an artificial soil mixture onto the slope using a seed spraying machine. In addition, slopes are sometimes covered with geotextile (Liu et al., 2016a), which prevents soil loss caused by rainwater erosion.

Vegetation-soil systems can improve soil shear strength, reduce soil loss, and improve slope stability, thus allowing vegetation cover to effectively facilitate slope ecosystem restoration (Chen et al., 2013; Yuan et al., 2016). However, researchers have different views on what kind of vegetation cover is best to improve artificial soil quality and enhance the structure stability of slopes. In recent years, an increasing number of researchers have focused on slope restoration based on the herb or shrub vegetation construction model (Matesanz and Valladares, 2007; Karim and Mallik, 2008; Lenka et al., 2012; Araújo and Costa, 2013; Yang et al., 2016; Chau and Chu, 2017). Some other researchers noted that woody plants, especially trees, can effectively prevent landslides (Stokes et al., 2009; Liang et al., 2017). Many researchers are concerned with the effects of a single vegetation restoration type on unstable slopes, while little research has been done to select suitable plant seeds for establishing a mixed vegetation cover on the cut slopes. Therefore, we are very interested in exploring what kind of mixed vegetation restoration types can efficiently improve artificial soil quality, enhance soil structure stability and promote the ecological restoration of cut slopes. This is a valuable study: (1) we can understand the practical application performance of different vegetation restoration types; (2) we can select the suitable plant seeds to spray onto the cut slopes to promote ecological restoration.

Many studies use different methods for soil quality evaluation, including the soil quality index (SQI) (Xu et al., 2009), the fuzzy association rule (Yue-Ju et al., 2010) and the soil management assessment framework (SMAF) (Wienhold et al., 2009). The SQI is a single index, combining a variety of information regarding soil (physical, chemical and biological parameters), which was established through principal component analysis (PCA) and ascending and descending functions (Bo-Jie et al., 2004; Zheng et al., 2005). The advantage of SQI is that the soil quality can be evaluated intuitively and accurately (Xu et al., 2009). In past studies, researchers have used the SQI to explore the impact of soil quality on crop yield in cultivated land and have evaluated the soil condition under different land use patterns (Askari and Holden, 2014; Paz-Kagan et al., 2014; Askari et al., 2015). The SQI was used with great success in many research areas, especially in the Mediterranean region of Europe (Imaz et al., 2010; Sánchez-Navarro et al., 2015). However, there are few applications of the SQI for assessing the artificial soil quality of cut slopes. In this study, we introduced the SQI to evaluate the artificial soil quality and then compared the SQIs to evaluate the effect of different vegetation restoration types on the artificial soil quality of cut slopes restored with OSSS. Previous studies (Chen et al., 2016; Huang et al., 2017) have reported that some physical and chemical parameters such as soil moisture content, bulk density, soil organic carbon, and clay content can reflect the changes in artificial soil quality. A soil enzyme is a biocatalyst that produces a specific biochemical reaction in the soil. Protease is a resource for nitrogen elements, which promotes plant growth (Woods, 1994). Sucrase activity can be used as an index for evaluating the degree of soil compaction and soil fertility (Bandick and Dick, 1999). Catalase and urease participate in the decomposition and synthesis of humus, animal and plant debris, and microbial residue decomposition (Ma et al., 2015). Therefore, we selected these crucial properties to use as the potential indicators of artificial soil quality assessment. Additionally, some indices were introduced for evaluating artificial soil structural characteristics. Soil erodibility can represent the ability of a soil to resist erosion (Meshesha et al., 2016) and can be used to characterize the movement of sediments (Rachman et al., 2003). Thus, soil erodibility is a good indicator for evaluating slope stability. Moreover, aggregate stability is a complex parameter and affects many soil properties, including water infiltration, aeration, compaction, water-retention, and hydraulic conductivity, and can be used to characterize slope stability (Abiven et al., 2009; Fattet et al., 2011).

In this study, cut slopes restored with OSSS of different vegetation restoration types were selected and compared with natural slopes. Our objective was to determine what kind of vegetation restoration types can better promote ecological restoration, improve soil quality and enhance slope stability. We then aim to present possible measures to improve this restoration technology and provide a theoretical and practical reference for the rehabilitation of railway cut slopes. Specially, we aimed (1) to use the structural stability indices and integrated soil quality index to evaluate structural stability and artificial soil quality of the cut slopes restored with OSSS of different vegetation restoration types and (2) to find the key indicators that promote the development of artificial soil and to improve the OSSS technique.

2. Materials and methods

2.1. Study area and experimental design

The study site is located near the Suining Railway Station in Suining, Sichuan Province (32° 32′N, 105° 32′E). It has a typical subtropical humid monsoon climate with an annual average wind velocity of 0.7 m/s, an annual average temperature of 17.4 °C, and an annual average rainfall of 927.6 mm. The study area is located in the low-mountain and hilly area of central Sichuan Basin, where the hilly area accounts for 82.4% of the total area. The soil at the study site was classified as Eutric Cambisol using the FAO–UNESCO system. The lower part of the soil rock layer is mainly limestone, and the upper part is mostly purple sand and mudstone, which belongs to a typical Mesozoic Jurassic strata. The topographic condition in the study site indicates that railway construction can inevitably lead to a large number of unstable bare cut slopes. Thus, artificial ecological restoration methods are often used to manage and enhance the stability of the slopes in order to ensure the safety of the people and properties near them. Outside soil spray seeding (OSSS) technology was used in the Suining section of the Suining-Chongqing line in 2003, the seed spraying machine sprayed the identical artificial soil mixture (plant seeds, artificial soil and soluble chemical fertilizers) onto these cut slopes (see Table 1 for the details of the mixing materials and proportions).

Based on a survey in 2015, the plant species were found to be different between the cut slopes (see Appendix. 1 for the main plant species in the railway cut slopes). Therefore, slopes with different vegetation restoration type were selected and compared with those found in slopes with natural conditions. These types were classified as follows (see Fig. 1a): (1) herbaceous-only vegetation restoration type slope (HS) (n = 3); (2) mixed vegetation restoration type slope I (MSI) (n = 3) composed of herbs and shrubs; (3) mixed vegetation restoration type slope II (MSII) (n = 3) composed of herbs, shrubs and trees, and (4)