Is it reasonable to use existing outside soil spray seeding technology to prepare artificial soil under slope aspect and area？

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Abstract

Knowledge about artificial soil nutrient of cut-slopes associated with slope aspect and landslide attributes is vital for understanding cut-slopes environmental ecosystem a establishing sustainable artificial soil management practices. Our study focuses on cut-slopes recovered by slope protect technology in alpine region, where slope aspect (east-, south-, west-, and north-facing slope) and landslide (non- and landslide) are dominant environment factors. Integrated matter-element model and path analysis were adopted to investigate the effects of slope aspect and landslide on the selected soil properties: pH, soil organic matter (SOM), alkali-hydrolysable nitrogen (AN), total phosphorus available phosphorus (AP), and available potassium (AK). Bo landslide had no significant effect on artificial pH ($p > 0.05$). Statistically significant differences were found for artificial SOM, AN, TP, AP, and AK between the slope aspect and landslide ($p < 0.05$). SOM, nitrogen (N), and potassium (K) were limiting factors for artificial soil nutrients on all slope aspect unde N was a limiting factor for artificial soil nutrients on all slope aspect under nor landslide. K was a limiting factor for artificial soil nutrients on all slope aspect under non-landslide, except for non-landslide-north-facing slope, while SOM was a limiting factor for artificial soil nutrients on non-landslide-north-facing slope. Landslide and slope aspect had a highly significant positive correlation with AN and AK, but negative correlation with AP. Therefore, it is necessary to formulate differen

management measures for different slope aspect and landslide to ac effective slope ecological restoration.

Key words: Cut-slopes; Outside soil spray seeding technology; Alpine region; Integrated matter-element model; Artificial soil nutrients

1 Introduction

Alpine regions are typical ecologically fragile areas in China. It ha mountain climate, with high altitude, low temperature, less rain, and hars conditions, which make it extremely difficult for plant growth (Zhong et al., 2003). Bare cut-slopes caused by highway construction, especially the Sic destroy the natural plants and deteriorate the ecological environment (Ai et al., 2012; Li et al., 2019). Soil nutrient status is the key to slope plant restoration (Li et al., 2018a). According to Jiang et al. (2021a), the bare cut-slopes still have no plants after 4 years of natural restoration, and bare cut-slopes of soil can be prone to degradation over time, they have a negative effect on the accumulation of nitrogen and phosphorus in the soil nutrient status of slopes in the Qinghai-Tibet Plateau. Against this background, outside soil spray seeding (OSSS) technology is widely used to recover the bare cut-slopes in the alpine regions (Ai et al., 2020; Zhu et al., 2020; Jiang et al., 2021b artificial soil, as a substrate that can provide necessary fertilizer for the growth of cut-slopes plants, is a core process to the OSSS technology (Chen et al., 2015; Zhu et al., 2020). In brief, artificial soil refers to soil in which backfill soil (rock fragmen agricultural soil), humus, composite material (cement and w chemical fertilizers (N, P, and K), plant seeds (*Poa annua*, *Elymus dahuricus*, and *Medicago sativa*), and fibers, are mixed in a certain proportion (Fu et al., 2018). Further researches have demonstrated that artificial soil nutrient were significant c between artificial plant species diversity index and vegetation type in the cu (Feng et al., 2016; Chen et al., 2019). Thus, the nutrient characteristics of artificial soil determine the vegetation restoration status of the bare cut-slopes in the alpine region.

Slope aspect affected slope microclimate, vegetation succession, water move and erosion, contribute to differences in precipitation, soil properties, and temperature (Birkeland 1984). Stenburg and Shoshany (2001) determined that slope aspect showed significant impacts on the plant composition, species richness, and plant density. Gou et al. (2015) demonstrated that slope aspect showed significant impacts on soil o matter (SOM), alkali-hydrolysable nitrogen (AN), and available phosphorus (AP) in hilly areas of south-western China. Ghosh et al. (2014) reported that slope aspect significantly affected soil organic carbon (SOC) and soil quality index. Nevertheless, most researches surveying the effects of slope aspect on soil nutrient have been implemented in natural slopes (Ghosh et al., 2014; Zhang et al., 2015; Wang et al., 2018), and few researches focused on the artificial soil nutrient in cut-slopes (Li et al., 2018b; Jiang et al., 2021b). Li et al. (2018b) demonstrated that artificial soil nutrient of cut-slopes changed with the slope aspect, while the artificial soil quality of south-facing slopes were worse than that of north-facing slopes. Jiang et al. (2021b) reported that artificial labile SOC fractions, enzyme activities, and total nitrogen (TN) were affected by the slope aspect after using the OSSS technology. Therefore, artificial soil nutrient of cut-slopes unde slope aspects must be estimated and supervised to formulate the optimal proportion of artificial soil addition and appropriate later management measures of cut-slopes under different slope aspects.

Slope failures which cause landslides are serious geo- especially to highway construction in alpine regions (Nich Meusburge and Alewell, 2008). Most studies focused on the slope stability and landslide mechanism in cut-slopes under the landslides (Brunsden et al., 1976; Yang et al., 2014). Landslide was the primary cause for the c (Mai et al., 2015), and the landslide soil has poor water and fertili performance (Li et al., 2018). Mandal et al. (2012) confirmed that velocity of restoration in soil properties after landslide was slower in the late successional stages than early stages. However, most studies focused on the slope soil nutrient content under the natural recovery after landslide (Mandal et al., 2012; Li et al., 2018), and few researches paid close attention to the artificial soil nutrient content under the slope protect technology after landslide. Wei et al. (2012) pointed that protection treatments and reinforcements were necessary to recovered the landslide slopes. Jiang et al. (2021b) indicated that artificial labile SOC fractions and enzyme activities were a landslides even after using the OSSS tech nutrient of cut-slopes under landslide must be estimated and supervised to formulate the optimal proportion of artificial soil addition and appropriate later management measures of cut-slopes under landslide.

Understanding artificial soil nutrient change of cut-slope under the slope aspect and landslide is of vital significance for making rational plan of maintaining artificial soil nutrients, especially in alpine region. In this region, the labor procurement and consumption, and mechanical t construction are all higher than other regions (Li et al., 2019; Lu and Cai, 2019). The precise preparation of artificial soil can effectively impr ecological restoration in alpine regions. Therefore, it is necessary to put forward later management measures for artificial soil of cut-slope. But, the influences of slope aspect and landslide on the change of artificial soil nutrients remain unknown in alpine region. Hence, the goals of this study were (i) to investigate the influences of slope aspect and landslide on change in artificial soil nutrients of cut-slope, (ii) to explore the limiting elements influencing the artificial soil nutrients, and management measures for artificial soil of cut-slope.

2 Methods

2.1 Soil sampling

This study was undertaken on the S301 roadway in Songpan county, located in the Sichuan province, China (32°49′24″-32°49′49″ N, 103°39′51″-103°40′48″ E), and has a cold temperature monsoon climate. Average elevation for this area is 3195 m. The study site have an average air temperature of 5.7 °C, maximum air temperatures of 16.3 °C, and minimum air temperatures of -21.1 °C. The freezing period extends from November to

February. Annual average precipitation is 720.0 mm, with the highest rainfall recorded between May to October. Annual sunshine duration is around 1827.5 hours.

The S301 roadway was built in 2003 and renovated in 2014. The whole highway was constructed in accordance with the level-2 highway standard, with a total length of 94.14 km, including 5.54 km for the newly built airport connection. OSSS technolog carried out in selected slosoil type of selected slopes was dominated by artificial soil, and the process mainly includes finishing highway slopes, layi protection nets, fixing them with anchor r (Yang, 2020)The depth of the artificial soil spraying was only 10 cm in the OSSS technique (Yang, 2020; Jiang et al., 2021b). Dominant vegetation included *Elymus dahuricus*, *Poa annua*, *Medicago sativa*, and *Elymus sibiricus* (Liu, 2007; Yang, 2020). The specific sampling point of this study is located on the newly built Jiuhuang Airport connecting line. Four slope types (three slopes per type were examined) were selected for investigation:a landslide-east-facing slope (L-E), a landslide-south-facing slope (L-S), a landslide-west-facing slope (L-W), and a landslide-north-facing slope (L-N) (Jiang et al., 2021b). A non-landslide-east-facing slope (NL-E), a non-landslide-south-fa slope (NL-S), a non-landslide-west-facing slope (NL-W), and a non-lan facing slope (NL-N) were selected as the comparison (Jiang et al., 2021b).

All samples were randomly gathered in September 2018. Using an S-shaped sampling method to gathered the samples along the S301 airport connectio replicate sample was collected from 20 points from upper, middle, and lower slope. The vertical height for all slopes was about 5-10 m, and gradient about 5°-15°. The length for all slopes was about 100 m. For preventing water evaporation, all sampl bagged in polyethylene plastic bags immediately after collection. After all samples were transferred to the lab, broken stone, animal, and plant debris were removed from samples before they were air-dried and manually screened through sieves.

2.2 Soil analysis

All soil analyses were undertaken using standard methods by Ba instance, soil pH was determined using potentiometric method, SOM was analyzed using the potassium dichromate oxidation-external heating method, AN was measured us alkaline hydrolysis diffusion method, TP was analyzed using the mo colorimetric method after digestion with H_2SO_4-$HClO_4$, AP was determined using the molybdenum blue colorimetric method after withdraw with $NaHCO_3$, available potassium (AK) was extracted using the flame photometric method after liquation with NaOH.

2.3 Data analysis

All statistical tests were analyzed and plotted using SPSS 16.0 (SPSS Inc., Chicago, IL, USA), R version 3.2.5, and SigmaPlot 12.0 (Sy respectively One-way analysis of variance (ANOVA) with a least significant difference (LSD) test were used to determine the differences among mean values for the different soil types. Significant levels were set at $p < 0.05$. Pearson's correlation coefficients was used to calculate correlations among soil nutrient, and significant levels we

$p < 0.01$. According to the method of Jiang et al. (2021a), the integrated matter-element model was used to assess artificial soil nutrient levels of all slopes. we used artificial soils data of TN (Supplement table 1) from Jiang et al. (experimental design is same with Jiang et al. (2021b). SOM, TN, AN, TP, AP, and AK were selected as evaluation indices and their weights were according to the supplement table 2. Path analysis was used to evaluate correlations between environmental factors and soil nutrient.

3 Results

3.1 Changes in soil nutrients

Our results indicate that aspect slope had no significant effect on artificial soil pH under non-landslide ($p > 0.05$, Table 1). Compared with NL-W, artificial SOM results for NL-E, NL-S, and NL-N recorded declines of 35.48% ($p < 0.05$), 8.85% ($p > 0.05$), and 52.78% ($p < 0.05$), respectively; TP results for NL-E, NL-S, and NL-N simila recorded increase of 20.35% ($p < 0.05$); AP results for NL-E, NL-S, and NL-N recorded declines of 27.31% ($p < 0.05$), 11.95% ($p > 0.05$), and 39.26% ($p < 0.05$), respectively (Table 2). In addition, SOM was very remarkably positively co ($p < 0.01$, Fig. 1). Compared with NL-E, artificial AN results for NL-S, NL-W, and NL-N recorded increase of 100.87% ($p < 0.05$), 74.03% ($p < 0.05$), and 123.23% ($p < 0.05$), respectively; AK results for NL-S, NL-W, and NL-N recorded increase of 103 ($p < 0.05$), 125.43% ($p < 0.05$), and 190.43% ($p < 0.05$), respectively (Table 2). In addition, AN was very remarkably positively correlated with AK ($p < 0.01$, Fig. 1).

Our results indicate that landslide had no significant effect on artificial soil compared with non-landslide under same slope aspects ($p > 0.05$, Table 1). Compared with NL-E, NL-S, and NL-W, artificial soil SOM results for L-E, L-S, and L-W recorded declines of 42.09%, 66.90%, and 68.53% ($p < 0.05$), respectively; while the difference between NL-N and L-N was not significant ($p > 0.05$, Table 2). Compared with NL-S, NL-W, and NL-N, artificial soil AN results for L-S, L-W, and L-N recorded declines of 50.72%, 42.79%, and 55.27% ($p < 0.05$), respectively; while the difference between NL-E and L-E was not significant ($p > 0.05$, Table 2). In addition, AN was very remarkably positively correlated with AK ($p < 0.01$, Fig. 2). Compared with NL-W, NL-S, and NL-N, artificial soil TP results for L-W, L-S, and L-N were not s ($p > 0.05$), while the difference between NL-E and L-E was significant ($p < 0.05$, Table 2). Compared with NL-E, NL-S, and NL-W, artificial soil AP results for L-E, L-S, and L-W recorded increase of 132.29%, 59.61, and 35.14% ($p < 0.05$), respectively; while the difference between NL-W and L-W was not significant ($p > 0.05$, Table 2). Compared with NL-W, NL-S, and NL-N, artificial soil AK results for L-W, L-S, and L-N significant difference ($p < 0.05$), while the difference between NL-E and L-E was not significant ($p > 0.05$, Table 2).

3.2 The artificial soil nutrient rating

Using the integrated matter element model to evaluate the artificial soil nu rating for understanding that is it reasonable to use existing OSSS technology to prepare artificial soil under slope aspect and landslide in alpine area? After calculating the comprehensive correlation of artificial soil nutrients, the artificial soil nutrient was judged according to the integrated correlations of the comprehensive artificial soil nutrients. Except for NL-W (nutrient trophic grade V), the artificial soil nutrient grades of the other slopes are all VI, which suggest that it is not reasonable to use existi OSSS technology to prepare artificial soil under slope aspect and landslide in alpine area (Fig. 3).

Further research results show that although the total nutrient levels of all slope artificial soils are similar (Fig.3), the lack of artificial soil nutrient limiting factors for each type of slope is different (Fig.4). Results in Figures 3 and 4 indicate that an imbalance i nutritional content from NL-E to L-N exists. NL-E and NL-S (nutrient trophic VI) were rich in TP, lacking TN, AN, and AK, indicating that N and K were limiting factors for artificial soil nutrients on NL-E and NL-S. NL-W (nutrient trophic grade V) were rich in TP, lacking TN, AN, and AK, indicating that N and K were limiting factors for artificial soil nutrients on NL-W. NL-N (nutrient trophic grade VI) were rich in TP, lacking SOM, TN, AN, and AP, indicating that SOM and N were limiting factors for artificial soil nutrients on NL-N. L-E, L-S, and L-W (nutrient trophic grade VI) were rich in TP, lacking SOM, TN, AN, and AK, indicating that SOM, N, and K were limiting factors for artificial soil nutrients on L-E, L-S, and L-W. L-N (nutrient trophic grade

VI) were rich in TP, lacking SOM, TN, AN, AP, and AK, indicating that SOM, N, and K were limiting factors for artificial soil nutrients on L-N. In general, artificial soils with a nutrient trophic grade of V and VI lacked TN and AN. In our study, all artificial soil types were rich in TP, which indicating that P was not limiting factor for artificial soil nutrients of slope in alpine area.

3.3 Path analysis

As shown in Fig. 5, Landslide had a highly significant positive correlation with AN, TN, AK, and SOM and it was significantly negatively correlated with AP, and no significantly correlated with pH. Slope aspect had a hi correlation with AN and AK and it was significantly negatively correlated with AP.

4 Discussion

Aspect slope significantly affects soil nutrient contents (Lei et al., 2019; Gao et al., 2020). For the northern hemisphere, the south-facing slope receives more sunlight and the temperature is high; the north-facing slope stores a lot of water and the temperature is lower (Mao et al., 2015). Our results indicate that aspect slo significantly affects artificial soil AN, TP, AP, and AK, but does not affect the artificial soil pH. Yang et al. (2020) showed that aspect slope significantly affects the soil AN of *Platycladus orientalis*, *Ziziphus jujube*, *Vitex negundo*, and *Quercus variabilis*. Fu et al. (2018) showed that the species diversity index of artificial p correlated with artificial soil nutrients. Li et al. (2018a) showed that slope vegetation matching patterns significantly affects artificial soil nutrient. Chen et al. (2021) showed that aspect slope did not affect alpine meadow soil TN and TP content, but significantly affects soil pH, this is inconsistent with the results of our study, which may be caused by different soil types and vegetation types.

In this study, SOM, AN, TP, and AK on non-landslide were higher than landslide under four slope aspects, while the change trend of AP was opposite, but had no effect on artificial soil pH, which is consistent with the results of Tan et al. (2019) and Duan et al. (2020). Duan et al. (2020) showed that landslide caused changes in soil microbia composition and soil enzyme activity, resulting in a decrease in soil AN and AP content. Jiang et al. (2021b) also acknowledged that landslides had an influence on soil urease and sucrase activity. Zhong et al. (2016) and Mao et al. (2017) belie earthquake landslides significantly reduced soil AN, TP, Results indicate that the artificial soil nutrient rating was NL-W>L-W; NL-E=L-E; NL-S=L-S; NL-N=L-N. N, K, and SOM were the limiting factors of artificial soil nutrients in all slopes under landslide. This is similar to the results of Sparling et al. (2003) a Cheng et al. (2016) that landslides will lead to lack of soil nutrients. Liu et al. (2014) researched that soil N was the limiting factor for slope vegetation r succession. Hu et al. (2018) found that soil TK was the main limiting factor affecting the growth of slope plant communities. Błońsk et al. (2018) believed that soil SOM can be used as an indicator of changes in soil physical and chemical properties of lands slopes.

Significantly, the soluble fertilizer used in artificial soil pr technology is N, P, and K in a ratio of 16:6:8 (Fu et al., 2018). However, the artificial soil of highway slopes in alpine region did not lack P, so the proportion of P can b appropriately reduced; on the contrary, it lacks N and K, so the proportion of N and K can be appropriately increased. At the same time, the highway slopes after the landslide lack SOM, so the humus content can be appropriately increased in the artificia preparation. In summary, the artificial soils of different slope aspects lack N and K in alpine region, which provides a more scientific theor management of artificial soils for the application of OSSS technology in alpine region.

5 Conclusions

Slope aspect and landslide had significant impacts on the SOM, AN, TP, AP, and AK, while no significant impact on pH. Compared with NL-E, NL-S, and NL-W, artificial soil SOM (AP) results for L-E, L-S, and L-W recorded declines of 42 (132.29%), 66.90% (59.61), and 68.53% (35.14%), respectively. Compared with NL-S, NL-W, and NL-N, artificial soil AN results for L-S, L-W, and L-N recorded declines of 50.72%, 42.79%, and 55.27%, respectively. Landslide had a highly significant positive correlation with AN, TN, AK, and SOM, correlation with AP. Slope aspect had a highly significant positive correlation with AN and AK, and correlation with AP. Moreover, SOM was very remarkably positively and c disturbance, and AN was very remarkably positively correlated wit

landslide disturbance and after landslide disturbance. In addition, SOM, N, and K were limiting factors for artificial soil nutrients on all slope aspect unde

N was a limiting factor for artificial soil nutrients on all slope aspect under nor

landslide. K was a limiting factor for artificial soil nutrients on all slope aspect under non-landslide, except NL-N, while SOM was a limiting factor for artificial soil nutrients on NL-N.

Declarations

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Competing interests

The authors declare that they have no competing interests.

Availability of data and material

The datasets used and analysed during the current study are available

corresponding author on reasonable request.

Code availability

Not applicable.

Authors' contributions

X Jiang and YW Ai contributed to the study conception and des preparation were performed by X Jiang, SH Ai, MK Zhu, BC Huang, XY collection and analysis were performed by X Jiang. The first draft of the manuscript was written by X Jiang. All authors read and approved the final manuscript.

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