

## Postprint: Effects of Vegetation Restoration on Road Cut Slopes in Alpine Regions

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### Abstract

This study investigates the vegetation restoration effects of thick substrate spraying technology and vegetated concrete spraying technology on the highway slopes of the Arongqi to Boketu section in the Daxing' anling region. The results indicate that: 1) Based on plant community composition and community similarity coefficient, the overall restoration effects of the two technologies are not significantly different, but the plant community on the vegetated concrete spraying slope more closely approximates natural conditions. 2) Also based on plant community composition and community similarity coefficient, the restoration effects of the two technologies differ significantly between shady and sunny slopes. 3) Appropriate increases in soil total nitrogen and organic matter content can promote plant community development, while increases in soil available phosphorus content inhibit its development. 4) The recommended suitable species combination includes *Artemisia argyi*, *Artemisia integrifolia*, *Leymus chinensis*, *Stipa baicalensis*, *Lespedeza daurica*, *Amorpha fruticosa*, and *Salix hsinganica*. This research can enhance the application of these two ecological restoration methods in this region, optimize species configuration, prevent secondary degradation, and provide a theoretical basis for subsequent maintenance and management.

### Full Text

### Preamble

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**Vegetation Restoration Effects of Rock Cutting Slopes in the Cold Region of China**

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## Abstract

This study evaluated the vegetation restoration effects of thick-layer substrate spraying and eco-concrete spraying techniques on highway slopes in the Arun Banner to Boketu section of the Daxing' anling region. By analyzing plant community composition, community similarity coefficients, Margalef index, Shannon-Weiner index, Pielou index, Jaccard index, and soil data, we aimed to understand successional stages and soil-plant relationships. The results indicate that: (1) While both techniques produced similar plant communities and similarity indices, eco-concrete slopes exhibited communities closer to natural levels; (2) Significant differences existed between shady and sunny slope communities for both techniques; (3) Appropriate increases in soil total nitrogen and organic matter promoted community development, whereas increases in soil available phosphorus inhibited it; (4) The overall restoration effects of both techniques were comparable, though eco-concrete spraying showed advantages. This research can improve application of both methods in this region, optimize species configuration, and prevent secondary degradation. Recommended species combinations include *Artemisia argyi*, *Stipa baicalensis*, *Lespedeza daurica*, *Amorpha fruticosa*, and *Salix hsinganica*.

**Keywords:** rock cutting slope; vegetation restoration; community diversity; community similarity; correlation

## Introduction

With China's rapid economic, scientific, and technological development, the national expressway network has become increasingly extensive. However, highway construction inevitably damages ecosystems, creating numerous high and steep slopes. Expressway construction generates approximately  $(2-3) \times 10^4$  m<sup>2</sup> of bare slope surface per kilometer, with slope areas growing at an annual rate of  $(5-7) \times 10^4$  m<sup>2</sup> since 2000. The United States and other developed countries pioneered slope ecological restoration, while Japan currently leads in restoration technology development. China's ecological restoration efforts, particularly for specialized environments like rock slopes, remain in an exploratory phase.

Rock slopes present unique challenges compared to soil slopes: they are typically high, steep, and have extremely poor soil conditions with high instability, making recovery exceptionally difficult. Current restoration techniques in China

include thick-layer substrate spraying, eco-concrete spraying, hydroseeding, liquid planting, geogrid planting, and honeycomb grid planting. Among these, thick-layer substrate spraying and eco-concrete spraying are widely applied due to their effective restoration outcomes, simple construction, and economic feasibility. However, research on these techniques remains insufficiently systematic and comprehensive, leading to practical challenges.

Cold regions present additional difficulties. Extremely low temperatures hinder plant growth, and many introduced species lack adequate cold hardiness, resulting in degraded artificial slopes, reduced vegetation cover, and failure of native species establishment. Secondary degradation often occurs after initial growth periods. This study selected the Arun Banner to Boketu expressway (hereafter “A-B Expressway”) in the Daxing’anling region to evaluate both restoration techniques, determine successional stages, and examine relationships between plant community diversity and soil nutrients, thereby improving regional application and preventing secondary degradation.

## 1. Study Area Overview

The study area is located in the Daxing’anling region of Inner Mongolia, where the A-B Expressway runs northwest-southeast following the Arun River valley. The region exhibits a cold temperate continental monsoon climate, representing China’s coldest zone with an average annual temperature of  $-5.6^{\circ}\text{C}$  and annual precipitation of 360–500 mm (80% concentrated in July–September). The frost-free period lasts only 90–110 days from late May to early September, resulting in a short plant growth cycle.

Soils are acidic (pH 5–6.5), primarily comprising dark brown coniferous forest soil, brown coniferous forest soil, and podzolized brown coniferous forest soil, with intrazonal meadow and bog soils also present. The harsh climate limits plant diversity. Dominant species include *Larix gmelinii* (Dahurian larch), *Betula platyphylla* (Asian white birch), *Pinus sylvestris* var. *mongholica* (Mongolian pine), *Vaccinium uliginosum* (bog bilberry), and *Tilia amurensis* (Amur linden). Mongolian flora elements such as *Stipa baicalensis* (Baikal needlegrass) are widespread, while Changbai flora elements like *Artemisia integrifolia* also occur.

## 2. Plot Setup

Due to construction constraints, the A-B Expressway slopes were restored using thick-layer substrate spraying and eco-concrete spraying techniques. All slopes were rock-cut, with gradients of 1:1.75 and heights of 2–20 m. Seeded species and aspect ratios included:

- **Thick-layer substrate spraying:** *Bromus inermis* (25%), *Medicago sativa* (12.5%), *Amorpha fruticosa* (10%), *Caragana microphylla* (12.5%), *Leymus chinensis* (12.5%), and *Lespedeza daurica* (12.5%)

- **Eco-concrete spraying:** *Agropyron mongolicum* (25%), *Artemisia tanacetifolia* (25%), *Amorpha fruticosa* (10%), and *Lespedeza daurica* (12.5%)

In early August 2014, vegetation and soil surveys were conducted on ten restored sections and adjacent natural slopes. Since no trees established on artificial slopes, only shrub and herb quadrats were established. At each plot center and four corners, 4 m × 4 m quadrats surveyed shrubs while 1 m × 1 m quadrats surveyed herbs, recording species composition, coverage, and frequency.

Soil samples were collected diagonally from multiple points along each slope to account for uneven nutrient distribution. Five sampling points per slope were established with duplicate samples at each point. Samples were taken at 0-20 cm depth, thoroughly mixed, and excess material discarded using the quartering method. Laboratory analyses measured total nitrogen (semi-micro Kjeldahl method), organic matter (dichromate oxidation), available phosphorus (molybdenum-antimony colorimetry), available potassium (NH OAc extraction), slow-release potassium (1 mol/L HNO<sub>3</sub> extraction), and soil moisture.

### 3. Data Analysis

Data were processed using Excel 2010. Species importance values were calculated to determine community diversity indices: Margalef richness index, Shannon-Weiner diversity index, and Pielou evenness index. Jaccard similarity coefficients quantified community similarity, where  $q = 0-0.25$  indicates extreme dissimilarity,  $0.25-0.50$  moderate dissimilarity,  $0.50-0.75$  moderate similarity, and  $0.75-1.00$  high similarity.

Plant community data were first analyzed using detrended correspondence analysis (DCA) in Canoco 5.0. Since the maximum gradient length exceeded 2.987, redundancy analysis (RDA) was selected to quantitatively describe relationships between slopes and between plant communities and soil factors. Correlations between diversity indices and soil properties were analyzed using SPSS 17.0.

## 4. Results

### 4.1 Slope Community Composition

Natural shady slopes were dominated by *Elymus dahuricus* (Dahurian wildrye), while sunny slopes showed similar patterns. Both restoration techniques produced broadly similar community compositions on sunny slopes, with *Artemisia argyi* (mugwort) as the dominant species. Shady slope communities were also similar between techniques but lacked shrub layers, unlike natural slopes.

All species from the seeding protocols successfully colonized sunny slopes, with 4-5 species invading shady slopes. However, natural dominant species like *Artemisia integrifolia* had not yet invaded artificial slopes. Community structure on sunny slopes included shrub layers, while shady slopes remained herba-

ceous. Artificial communities showed more uniform horizontal distribution than natural slopes.

Similarity analysis revealed: - Thick-layer sunny vs. eco-concrete sunny slopes: extremely similar (0.9231) - Both techniques' shady slopes: extremely similar (0.8750) - Thick-layer sunny vs. shady slopes: moderately dissimilar (0.4375) - Both artificial sunny slopes vs. natural sunny slopes: moderately dissimilar (0.3810-0.4000) - Artificial shady vs. natural shady slopes: extremely dissimilar (0.2000-0.2381)

## 4.2 Community Diversity Indices and Soil Properties

**Richness:** All shady slopes showed lower richness than sunny slopes, with minimal differences between restoration techniques. Most sites exhibited significant aspect differences.

**Diversity (Shannon-Weiner):** All shady slopes had lower diversity than sunny slopes, with substantial differences. Compared to natural slopes, artificial slopes showed lower diversity but higher evenness.

**Soil nutrients:** - Total nitrogen: 3B > 7B > 2B > 6A > 3A > 6B - Organic matter: 8A > 3A > 8B > 7B > 7A > 6B > 3B - Available phosphorus: All shady slopes exceeded sunny slopes, with 3A > 3B > 7A > 6A > 8A > 2A > 2B > 7B > 6B - Soil moisture: All shady slopes exceeded sunny slopes

Natural slopes generally had higher total nitrogen, organic matter, and slow-release potassium than artificial slopes, but lower available phosphorus.

**Correlations:** - Richness: extremely significantly positively correlated with total nitrogen ( $r = 0.981$ ) and slow-release potassium ( $r = 0.933$ ); extremely significantly negatively correlated with available phosphorus ( $r = -0.942$ ) - Diversity: extremely significantly positively correlated with total nitrogen ( $r = 0.800$ ) and organic matter ( $r = 0.787$ ); extremely significantly negatively correlated with available phosphorus ( $r = -0.903$ ) - Evenness: negatively correlated with total nitrogen, organic matter, and moisture; positively correlated with available potassium and phosphorus

RDA analysis confirmed these relationships, showing total nitrogen and organic matter promoted community development while available phosphorus inhibited it.

## 5. Discussion and Conclusion

Although both techniques produced similar overall restoration effects, eco-concrete spraying created communities more similar to natural ones. The primary differences occurred between shady and sunny slopes rather than between techniques. Sunny slope communities from both techniques were extremely similar to each other and more similar to natural communities than shady slopes, indicating more advanced succession on sunny aspects.

Soil analysis revealed that appropriate increases in total nitrogen and organic matter promote community development, while excessive available phosphorus inhibits it. In cold regions, phosphorus is often over-applied to promote rapid root growth and winter survival, but this practice may suppress long-term community development. The decline of *Leymus chinensis* (a natural dominant species requiring high nitrogen and organic matter) on artificial slopes likely reflects this nutrient imbalance.

To improve restoration outcomes, we recommend: (1) reducing phosphorus application; (2) increasing nitrogen and organic matter inputs during maintenance; (3) using pioneer, mid-successional, and climax species in combination to accelerate succession and enhance stability. Based on community composition and species importance values, optimal species for this region include *Artemisia argyi*, *Stipa baicalensis*, *Lespedeza daurica*, *Amorpha fruticosa*, and *Salix hsinganica*. These findings provide a theoretical basis for improving restoration techniques, optimizing species configuration, and preventing secondary degradation in cold region rock slopes.

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**Note:** Figure and table markers ([Figure 1: see original paper], , etc.) have been preserved as instructed and correspond to the original Chinese manuscript's reference points.

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