



Article Evaluation of Vegetation Restoration along an Expressway in a Cold, Arid, and Desertified Area of China

Chunfeng Jia^{1,2,3}, Bao-ping Sun^{1,*}, Xinxiao Yu¹ and Xiaohui Yang⁴

- ¹ School of Soil and Water Conservation Beijing Forestry University, Beijing 100083, China; jiachunfeng@bjfu.edu.cn (C.J.); yuxinxiao111@bjfu.edu.cn (X.Y.)
- ² Shanxi Environmental Protection Institute of Transport (co., LTD.), Taiyuan 030006, China
- ³ Shanxi Transportation Research Institute, Taiyuan 030006, China
- ⁴ Chinese Academy of Forestry, Beijing 100091, China; xiaohuiyang@caf.ac.cn
- * Correspondence: sunbaoping@bjfu.edu.cn; Tel.: +86-010-6233-8068

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Abstract: Vegetation restoration plays a significant role in the restoration of expressways in the arid zone of China, but we still do not know which soil and vegetation types are most effective. We investigated soil particle size (SPZ), volume weight of the soil (VWS), soil water content (SWC), total porosity of soil (TP), soil organic matter (SOM), water erosion (W_rE), and wind erosion (W_dE) of eight sites (S1–S8) and evaluated them using the gray correlation method (GCM). Based on our results, the average SWC of the treatments ranged from 9.6% to 18.8%, following the order S4 > S5 > S8 > S6 > S3 > S7 > S1 > S2. The average SPZ of soils in S1, S2, S4, S5, S6, and S8 was larger, ranging from 0.23 to 0.68 mm, while that of soils in S3 and S7 was smaller, ranging from 0.01 to 0.09 mm. The TP in different treatment areas ranged from 50% to 60%, which is not conducive to soil and water conservation. The SOM levels varied widely among the different soils and were always below the threshold levels established by the second National Soil Census, rendering the soils not suitable for plant growth. The $W_r E$ (36–80 t/ha) was greater than the $W_d E$ (7–24 t/ha). In general, to achieve high soil and water conservation outcomes in this area, S1 and S7 offered the best protection benefits in terms of soil and water conservation.

Keywords: benefit evaluation; gray correlation method; soil erosion; soil physical properties

1. Introduction

The construction of expressways inevitably destroys the surface vegetation, leading to significant ecological problems such as soil erosion and landscape degradation [1–3]. In this sense, vegetation restoration along expressways is crucial to stabilize the roadbed, improve the road environment, and enhance the aesthetic properties of such areas [4–6]. During construction, the soil structure is largely destroyed; the surface soil in the cutting slope was mixed with gravel, parent material, and, in some cases, even rocks [7]. As a result, the surface temperature difference between day and night is relatively high, physical weathering is extreme, and evaporation is high; consequently, precipitation easily initiates runoffs [8,9].

In this sense, vegetation restoration along expressways is challenging. Previous studies have taken a series of measures to restore expressway slopes. The traditional forms of slope vegetation protection include grass planting [10], three-dimensional vegetation networks [11], masonry stone wall establishment [12], skeleton grass planting [13], vine plant protection [14], and geogrid grass planting [15]. Slope grass planting is characterized by a low survival rate, high maintenance costs, and the frequent degradation of grass seeds, while shrub planting is restricted by the water and

nutrient conditions of the slope [14]. Inevitably, such approaches led to a low protection effect of the slope. Some expressway greening projects were only possible with the use of engineering work [15], with large investments. Also, over time, with rock weathering, concrete aging, and steel bar erosion, the protection effects become weaker [16,17]. In the northern regions of China, cutting slopes are also highly vulnerable to wind erosion [18,19]. Especially in the greening of expressways in arid, cold, and desertified areas, this problem is more prominent and mainly manifests in the following aspects: Firstly, the project implementers emphasize short-term effects while neglecting long-term effects [20], which directly leads to the phenomenon of "1 year green, 2 years yellow, 3 years withered, and 4 years dead". Secondly, project implementers overemphasize the quantity of greening. For example, in some arid areas, the emphasis was also on vegetation coverage, and especially in the south, evergreen trees have been planted extensively, often with unsatisfactory results. Thirdly, plant species selection and allocation were unreasonable [21], without any specific norms and standards, mainly copying the model of landscape greening and ignoring the natural laws of ecosystem and plant growth, which often resulted in unsatisfactory outcomes.

To reduce the environmental impacts of expressway construction and to improve the restoration of the damaged areas, it is crucial to employ new technologies, especially in cold, dry, and desertified areas. In this context, we included seven indices, namely volume soil weight, total porosity, soil moisture content, soil particle size, soil organic matter, water erosion, and wind erosion, from eight different treatment areas to evaluate the soil and water conservation benefits, using the gray correlation method (GCM) [22]. In this study, we summarize a set of technical methods for the ecological restoration of expressway areas in cold, dry, and desertified loess areas. The results of our study are of great significance for the restoration of vegetation along expressways, providing a reference for greening technology in other construction projects in cold, arid, and desertified areas and for technological progress of the vegetation restoration industry in general.

2. Study Sites

The study area is located along the Dahu Expressway (113.275° E and 39.936° N) in Datong City, Shanxi Province, a typical loess plateau area in China (Figure 1), at an elevation range from 1320 to 1170 m. The climate is north-temperate semi-arid continental monsoon climate. Due to the monsoon and high pressure on the Siberian and Mongolian plateau, there is little snow; the area experiences mild temperatures in winter, drought and windiness in spring, hot and rainy summers, and cool autumns. Average annual precipitation is 399 mm, of which more than 60% fall from July to September. Average annual temperature is 6.1 °C, with minimum and maximum temperatures of -29.5 and 34.5 °C, respectively. The daily temperature difference is 13.0 °C, with a frost-free period of 125 days. The study area can be divided into five geomorphic units, including loess hilly area, intermountain valley plain area, erosion and denudation high hilly area, valley plain area, and alluvial and flood plain area. The soil is mainly weathered rock soil, coarse silty soil, collapsible loess, and liquefaction soil of saline soil with sandy soil (Reference to China Soil Classification System). The main tree species are Pinus tabulaeformis, Larix gmelinii, and Pinus sylvestris var. mongolica. The shrub species mainly include Hippophae rhamnoides Linn. and Caragana korshinskii, while the most abundant herb genera are Carex and Artemisia. The above information was obtained by consulting local historical meteorological data and the respective yearbook.



Figure 1. Geographic map of the study area. The numbers 1–8 represent the treatments S1–S8.

3. Materials and Methods

3.1. Experimental Design

Because the soil and vegetation were completely destroyed during the construction of roads and slopes, the developers filled the slopes with soil and planted shrubs to restore the ecological environment. During the implementation of the project, four kinds of soils, including weathered rock soil, coarse silty soil, collapsible loess, and liquefaction soil of saline soil with sandy soil were filled (Figure 2), and two plant species (*H. rhamnoides Linn.* and *C. korshinskii*) were planted. To determine which soil and vegetation allocation provided better soil and water conservation benefits, eight representative treatment areas were selected according to the actual situation of the project area. Specific information on the soil and vegetation allocation in each treatment area is shown in Table 1.

Table 1. Basic information of the treatments along the expressway in Datong City, ShanxiProvince, China.

Number	Treatments	Specification (m)	Soil Type	Soil Thickness (cm)	Plant Species	Slope Ratio
1	S1	10×20	Weathered rock soil	43		
2	S2	10×20	Coarse silty soil	40	C 11	
3	S3	10×20	Collapsible loess	45	C. Korsninskii	
4	S4	10×20	Liquefaction soil of saline soil with sandy soil	39		1:1.5
5	S5	10×20	Weathered rock soil	43		
6	S6	10×20	Coarse silty soil	40	H. rhamnoides	
7	S7	10×20	Collapsible loess	45	Linn.	
8	S8	10×20	Liquefaction soil of saline soil with sandy soil	39		



Figure 2. Filled soil in the different treatments: S1 and S5 were the weathered rock soil; S2 and S6 were the coarse silty soil; S3 and S7 were the collapsible loess; S4 and S8 were the liquefaction soil of saline soil with sandy soil.

3.2. Soil Sample Collection

All samplings and erosion observations were performed in 2013. For the eight treatments along the expressway, nine sampling points were selected for each treatment. At each sampling point, soil samples were collected from the undisturbed original slope surface using a ring knife at depths of 0–20 cm, 20–40 cm, 40–60 cm, and 60–80 cm. The samples were brought to the laboratory to determine the volume weight of soil (VWS) and total porosity (TP). Additional soil samples were collected using an aluminum box to measure the soil moisture content (SWC) at the four soil depths, using the dry weighing method [23], and to determine soil organic matter levels via the potassium dichromate method [24]. Three soil samples were collected from each soil layer for each analysis.

3.3. Determination of Soil Physical Properties

3.3.1. Total Soil Porosity

To measure soil porosity, we opened the lower cover of the ring knife (with the mesh end), put it onto filter paper, and immediately weighed the sample (m_1) . Subsequently, we removed the upper cover of the ring cutter and placed the mesh end of the ring cutter into the basin. The height of the water layer in the bowl was up to the edge of the knife (not submerged). After 12 hours of water absorption, we removed the ring knife, covered the lid, and weighed the sample again (m_2) . After weighing, the ring cutter (bottom end of the mesh) was placed in a flat pan with dry sand and weighed (m_3) after 12 h. After weighing, the ring knife (mesh side down) was placed in a flat pan again and weighed (m_4) immediately after infiltration for 12 h. The weighed ring knife cover was opened, placed in an oven at 105 °C for 24 h, covered, and weighed (m_5) . Subsequently, soil porosity was calculated as follows:

$$P = \left(\frac{m_2 - m_5}{v}\right) \times 100\% \tag{1}$$

where P is total porosity (g/cm³) and v is the volume of the ring cutter.

3.3.2. Volume Weight of The Soil

The VWS was measured using the ring knife method [25]. We ensured that the soil in the ring cutter was not disturbed during each operational step. The ring cutter with the soil sample was placed in an oven at 105 °C and dried to constant weight; afterwards, the ring knife with soil samples (m_{1j}) and the soil samples (m_{2i}) were weighed separately, and the VWS was calculated as follows:

$$VWS = \frac{\sum_{j=1}^{3} (m_{1j} - m_{2j})}{3v}$$
(2)

where the v is the volume of the ring cutter, and J = 1, 2, and 3 is the repeat number of the same soil layer.

3.3.3. Soil Organic Matter

We used the potassium dichromate oxidation-external heating method to determine soil organic matter (SOM). Briefly, the soil mixture is boiled with potassium dichromate oxidizer and sulfuric acid (95%) in an oil bath at 170–180 °C for 5 min. The carbon in the SOM was oxidized to carbon dioxide by potassium dichromate, while the hexavalent chromium in the potassium dichromate was reduced to trivalent chromium. The remaining potassium dichromate was then titrated with standard solution of ferrous oxide. According to the amount of ferrous sulfate consumed by potassium dichromate before and after oxidation of organic carbon, the content of organic carbon was calculated and converted into SOM.

3.3.4. Soil Erosion

During the observation period, runoff barrels were used to collect runoff and sediment samples in the eight treatment plots. Weighing–sedimentation–drying–weighing and sampling–drying–weighing were used to correct the runoff and sediment yields, respectively. Hydraulic erosion per hectare was obtained through the area of the plot [26]. Secondly, wind erosion was measured via the cutting method [27]. The first choice is to record the depth of cutting, measure the change depth of cutting after the observation period, and, finally, calculate the wind erosion.

3.3.5. Evaluation of Benefits of Soil and Water Conservation of Different Treatments by the GCM

Here, X_0 is the reference series and X_i the comparison series. The value of the reference series represents the maximum value of each test indicator. First, we calculated the absolute value of the difference between each corresponding point of comparison sequence X_i and reference sequence X_0 , and the GCM was evaluated as follows:

$$\Delta \mathbf{i}(k) = \left| \mathbf{X}_0(k) - \mathbf{X}_i(k) \right| \tag{3}$$

$$X_0 = \{X_0(1), X_0(2), X_0(3), \dots, X_0(n)\}$$
(4)

$$X_i = \{X_i(1), X_i(2), X_i(3), \dots, X_i(n)\}, i = 1, 2, 3, \dots, m.$$
(5)

When using this approach, the actual value of each index must be converted into an evaluation value, and the original data should be processed without a dimension, according to the reference series data. On the one hand, the influence brought by each index dimension should be removed [28]; however, on the other hand, this indicator can also reflect the relative dominance of the community.

We used the formula $X_i(k)$ = original data sequence/reference data sequence to perform non-dimensionalization, reducing all data return to the [0,1] interval.

Subsequently, we determined the second-order maximum difference and the second-level minimum difference and calculated the correlation coefficient:

$$\xi_i(k) = rX_0(k), X_i(k) = \frac{\min\min\Delta_i(k) + \rho\max\max\Delta_i(k)}{\Delta_i(i) + \rho\max\max\Delta_i(k)} = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0,i}(k) + \rho\Delta_{\max}}$$
(6)

where $\xi_i(k)$ represents the relative value of the k point comparison curve (X_i) and the reference curve (X₀); that is, the X_i's correlation coefficient of X₀ at point k. When $\Delta 0$, i(k) represents the absolute value of the X₀ sequence and the X_i sequence at the k point, $1 \le i \le m$, m was positive; Δmin and Δmax , respectively, represent the minimum and maximum values of the absolute difference of all comparison points in each point; ρ is the resolution coefficient ranging from 0–1. Here, ρ was artificially set to 0.5 (the artificial coefficient for qualitative analysis) to weaken the distortion effect caused by the excessively large maximum value to increase the significance of the difference between the correlation coefficients:

$$\mathbf{r}_i = \frac{1}{n} \sum_{k=1}^n \xi_i(k) \tag{7}$$

where r_i indicates the degree of gray correlation; ξ indicates the gray correlation coefficient.

To measure the importance of each index more realistically and objectively, the coefficient of variation W_i was calculated using the coefficient of variation method:

$$W_i = \frac{r_i}{\sum r_i}.$$
(8)

Subsequently, we calculated the gray comprehensive evaluation value G (k) with the correlation degree value:

$$G_k = \sum_{k=1}^n \xi_i(k) \mathbf{W}_i.$$
⁽⁹⁾

3.4. Statistical Analysis

Statistical analyses were performed using the software package SPSS 16.0. Descriptive statistics was used to calculate the mean and standard deviations for each set of replicates. First, a two-way ANOVA was used to analyze the differences in the SOM and SWC (n = 27 for each soil stratum), with treatment and soil depth as the independent factors. Two-way ANOVA was also used to analyze the differences in the SPT (n = 27 for each soil stratum), with treatment and soil particle size as independent factors. One-way ANOVA was also performed to test the effects of VWS, TP, W_rE, and W_dE on all treatments. All data were tested for normal distribution and homogeneity of variance analysis, meeting the requirements of variance analysis.

4. Results and Discussion

4.1. Basic Meteorological Characteristics

The study area is a temperate continental monsoon climate region, with an annual average precipitation of 384.02 mm. In 2013, average precipitation reached 418.7 mm, which was 9.03% higher than annual average precipitation (Figure 3). Precipitation from June to September was 296.1 mm, accounting for 70.71% of the total precipitation. Daily average precipitation was 1.14 mm, and maximum precipitation was 45.9 mm on September 9. During 2013, average daily temperature was 2.1 °C, with a single-peak "convex" pattern with seasonal changes. This gradually increased from January to July, reaching a maximum of 26.7 °C on July 30. After this peak, temperatures gradually decreased. The average daily wind speed was 1.04 m/s, with distinct differences between the seasons.



Figure 3. Precipitation, temperature, and wind speed in the study area along the expressway in Datong City, Shanxi Province, China, in 2013.

4.2. Weight Percentage of Soil Particle Size Under Different Treatments

Previous studies have stated that with decreasing soil particle diameter, the soil cohesiveness gradually increased [29–31]. According to the international classification standard of particles, when a particle of a sample has a diameter of 2–64 mm, it is called "gravel" [32]. In our study, the distribution of the particle size of the samples greatly varied among the different treatments (Figure 4). Site S2 contained the largest amount of gravel among all treatments, accounting for 25.35%. In the other treatments, the proportion of gravel was smaller, or gravel was completely absent. Particles with a diameter of 0.05–1 mm were most abundant in S8, with a significant difference when compared to the other treatments (p < 0.05). The weight percentages of d = 0.05–1 mm were 48.86%, 35.18%, 41.35%, 50.28%, and 61.72%, respectively, for the treatments S1, S2, S3, S7, and S8, which were significantly higher than those for the other particle size compositions (p < 0.05). The proportions of particles with a diameter of <0.005 mm were 39.52% and 38.65%, respectively, in the treatments S4 and S5, which were significantly higher than those in the other treatments (p < 0.05). Lu et al. also found that the size of the soil particles in the soil matrix differed; this was not only the case for the surface soil layers, but also for soil porosity in general [33]. Sandy soil contains coarse gravel and has a high soil porosity. On the contrary, the permeability of loam or clayey soil is lower than that of sandy soil, facilitating surface runoff [34]. Soil particle size and runoff are closely related, and a favorable soil particle size composition can effectively maintain water, nutrients, and organic matter [35]. According to our results, most of the particles with a diameter of more than 2 mm retain the original mineral composition of the parent rock. There are few available mineral nutrients, and the ability to absorb water was also poor. When the content of gravel in the soil exceeds 20% of the total volume of sample, changes in the temperature of the sample will be aggravated, and the water-holding capacity of the soil will be reduced [36].



Figure 4. Variation in weight percentage of particle size of the samples under different treatments along the expressway in Datong City, Shanxi Province, China, in 2013. d represents soil particle diameter.

4.3. Variations in Volume Weight of the Soil and Total Porosity under Different Treatments

The volume weight of the soil (VWS) can be used as an indicator of soil solidity under certain conditions. At the same soil texture, soil with a low volume weight is relatively loose, while soil with a high VWS tends to be firm [36]. Generally, VWS varies greatly with soil texture, structure, and tightness [37]. Total porosity (TP) represents the percentage of soil porosity of the total soil volume. The amount of soil pores is related to the water permeability, air permeability, thermal conductivity, and compactness of the soil [38]. In our study, VWS and total porosity differed among the different

treatments (Figure 5). The VWS was highest in S8, reaching 1.60 g/cm³, and lowest in S3, with a value of 1.34 g/cm³, with a difference of 19.4%. The VWS of S1 was 1.54 g/cm³, with no significant difference between S1 and S7 (p > 0.05). The VWS values of S2 and S4 were 1.47 and 1.46 g/cm³, respectively, also without a significant difference (p > 0.05). The VWS values of S1 and S8 were lager, while those of S3 and S5 were smaller, indicating a low soil compactness of S3 and S5, which is more suitable for plant growth. The TP values of S3, S5, and S8 were relatively high with 59.12%, 58.97%, and 58.97%, respectively, while that of S4 was 53.12% and therefore smaller than the values found for S3, S5, and S8. Generally, the TP ranged between 50% and 60%, and the texture was loose, which may not be conducive to water and fertilizer conservation.



Figure 5. Variations (± SD) in volume weight of the soil and total porosity under different treatments along the expressway in Datong City, Shanxi Province, China, in 2013. VWS and TP represent volume weight of the soil and total porosity, respectively.

4.4. Variations in Soil and Water Content and Soil Organic Matter under Different Treatments

The soil water content (SWC) is mainly affected by both precipitation and evaporation [39]. In our study area, SWC and SOM levels differed greatly among the different treatments, most likely because of the inherent soil characteristics. The SWC levels increased with increasing soil depth, which might be explained by the high evaporation of the surface soil, resulting in low water content. However, SOM levels decreased with increasing soil depth (Figure 6). This, owing to these surface soil layers, can easily be supplemented with organic matter. The changes in SWC among treatments ranged from 9.6% of the average SWC of S2 to 18.8% of the average SWC of S4. The average SWC of S4 was twice the average SWC of S2. The average SWC levels of S1, S3, S5, S6, S7, and S8 were 10.3%, 14.5%, 17.9%, 14.8%, 12.7%, and 16.3%, respectively, following the order S4 > S5 > S8 > S6 > S3 > S7 > S1 > S2. The average SOM level of S8 was 0.40%, which was highest than in the other treatments, but still relatively low when compared with the lowest Grade 6 of the second National Soil Census and related standards (<0.6%) [40]. The average SOM content of S6 was 0.17%, which was 57.5% lower than that of S8. The average SOM levels of S1, S2, S3, S4, S5, and S7 were 0.23%, 0.25%, 0.23%, 0.20%, 0.19%, and 0.22%, respectively, following the order S8 > S2 > S1 > S3 > S7 > S4 > S5 > S6. The nutrient contents of the treatments were relatively low, without SOM, and the soils are therefore not suitable for the growth of newly transplanted. Most shrub species, when transplanted into a new environment, require adequate SOM levels to adapt and grow, in contrast to naturally growing shrubs, which have adapted to these environments through natural selection.



Figure 6. Variations (± SD) in soil and water content and soil organic matter under different treatments along the expressway in Datong City, Shanxi Province, China, in 2013. **a** and **b** represent the variations in soil and water content and soil organic matter, respectively.

4.5. Variation in Soil Erosion under Different Treatments

During the observation period, the water erosion ($W_r E$) of the different treatments varied because of the different soil properties. Throughout the study area, water erosion was greater than wind erosion (W_dE) , ranging between 36 and 80 t/ha, while W_dE was between 7 and 24 t/ha (Figure 7). According to the classification of soil erosion intensity in China (SL190–2007), this area is moderately affected by soil erosion. The average $W_r E$ of S4 was the largest (69.70 t/ha), while that of S3 was the smallest (39.70 t/ha). The $W_r E$ of S3 was 43.03% lower than that of S4. The WE values of S2, S6, and S7 were relatively similar and reached about 50 t/ha. In S3 and S4, wind erosion was lower (8.10 and 8.63 t/ha, respectively), while at S7 and S8, it was higher (21.91 and 21.75 t/ha, respectively). The W_dE values of S7 and S8 were 2.70 and 2.52 times higher than those of S3 and S4, respectively. We found no significant differences in W_dE among S1, S2, S5, and S6 (p > 0.05). With increasing soil porosity, WrE gradually decreased; generally, these two factors are not correlated [41]. The larger porosity of the surface soil facilitated the infiltration of runoff on the slope, thereby reducing runoff on the slope and the scouring force of runoff on the surface soil [42]. At the same time, the infiltration water also increased the erosion resistance of the surface soil [43]. Although there were numerous factors affecting slope surface erosion, and the interaction among them is more complex, in general, the pore size of the surface soil plays a role in inhibiting surface erosion.



Figure 7. Variation $(\pm$ SD) in soil erosion amount under different treatments along the expressway in Datong City, Shanxi Province, China, in 2013. **a** and **b** represent the variations in water erosion and wind erosion during the experimental period.

4.6. Evaluation of Different Soil and Water Conservation Measures Using the GCM

The results of comprehensive evaluations can directly reflect the effects of soil and water conservation measures [22,44,45]. The order of gray comprehensive evaluation values in the eight conditions was as follows: S1 (0.7593) > S7 (0.6995) > S3 (0.6656) > S8 (0.6516) > S5 (0.6485) > S2 (0.6385) > S4 (0.6377) > S6 (0.6194) (Table 2). This indicates that in S1, the soil and water conservation benefits were highest, suggesting the use of this soil in restoration programs in this area. Basically, these results lead us to infer that weathered rock soil and collapsible loess can be used when repairing slopes. In terms of plant species, *C. korshinskii* and *H. rhamnoides* Linn. were planted separately to achieve the best soil and water conservation benefits. The gray comprehensive evaluation values of each index were VWS (0.7376) > TP (0.7284) > SPZ (0.7233) > SWC (0.5777) > SOM (0.466) > W_rE (0.4294) > W_dE (0.369). The relationship between soil bulk density and total porosity was the most significant one, indicating that soil porosity and soil bulk density have the greatest impact on the effect of soil and water conservation measures. When repairing slopes, organic fertilizer can be applied to enhance plant growth and improve soil conditions. Additionally, adequate irrigation is necessary to support plant development.

Table 2. Correlation degrees and correlation coefficients of each evaluation index. SPZ, VWS, TP, SWC, SOMC, W_rE , W_dE , and G (k) represent soil particle size, volume weight of the soil, soil water content, total soil porosity, soil organic matter, water erosion, wind erosion, and gray comprehensive evaluation value, respectively. The parameter ri and Wi indicate the degree of gray correlation and the coefficient of variation, respectively.

Treatments	SPZ	VWS	ТР	SWC	SOMC	W _r E	W _d E	G (k)
S1	0.7489	0.8513	0.8321	0.5286	0.3427	0.3388	0.341	0.7593
S2	0.5475	0.7981	0.6162	0.5955	0.3414	0.3538	0.336	0.6385
S3	0.8005	0.8142	0.784	0.5115	0.3576	0.4026	0.3492	0.6656
S4	0.6653	0.6316	0.7106	0.8678	0.5932	0.6929	0.3376	0.6377
S5	0.6872	0.7469	0.7106	0.8714	0.6494	0.4797	0.3347	0.6485
S6	0.6872	0.6498	0.7106	0.5496	0.5772	0.487	0.4074	0.6194
S7	0.8595	0.6427	0.7251	0.555	0.6653	0.3745	0.7557	0.6995
S8	0.8477	0.8864	0.7988	0.5079	0.6818	0.3576	0.7233	0.6516
ri	0.7233	0.7376	0.7284	0.5777	0.466	0.4294	0.369	0.5768
Wi	0.1975	0.1014	0.1389	0.1577	0.1272	0.1173	0.16	0.5661

5. Conclusions

We observed significant differences in soil and water conservation benefits among different soil types and two shrubs species. When the gravel content of the soil exceeded 20% of the total soil volume, the changes in soil temperature are aggravated, resulting in a reduced water holding capacity. Based on the soil porosity in the area, water and organic matter conservation are not optimal, and in some sites, the soil condition was not suitable for plant growth. Although we found relatively different organic matter levels in the experimental sites, all levels were beyond the threshold values established by the second National Soil Census. Based on the poor water and organic matter status, plant growth is severely limited. Soil erosion resistance varied greatly among the different sites, and slope protection is crucial to ensure soil and water conservation in this area. The results of the comprehensive evaluation value indicate that the sites of S1 and S7 provide the best soil and water conservation benefits. This also shows that the region can achieve high soil and water conservation benefits through the two allocation modes for slope protection. Weathered rock soil and collapsible loess can be filled in to protect slopes in this area, and subsequently, the two shrub species *C. korshinskii* and *H. rhamnoides* Linn. can be planted separately to achieve optimum protection and to conserve soil and water.

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