

## Soil Nutrient Effects of Artificial Sand-Fixing Vegetation in the Mu Us Sandy Land (Postprint)

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### Abstract

To explore the influence patterns of different artificial sand-fixing vegetation types on soil nutrients in the Mu Us Sandy Land, six typical artificial sand-fixing vegetation types in the Mu Us Sandy Land were selected as research objects. Through analysis and calculation of the physicochemical properties of 0-100 cm soil and the Soil Nutrient Index (SNI) of six different artificial sand-fixing vegetation forests, the research results show that: the soil bulk density of the six artificial sand-fixing vegetation types showed no significant differences, exhibiting weak variation. Soil organic carbon (SOC) and total nitrogen content (TN) both showed higher values in the surface layer than in the deeper layers, total potassium (TK) content showed no significant differences, and phosphorus (P) content showed no obvious pattern. Soil organic carbon density in the 0-20 cm layer was significantly higher than in other soil layers, showing obvious surface accumulation. The cumulative storage of soil organic carbon (SOC) in the 0-100 cm layer, except for bare sand land, varied with soil depth, and could be simulated by a logarithmic function [ $y = a \ln(x) + b$ ,  $R^2 > 0.96$ ] for the six artificial sand-fixing vegetation sample plots. The Soil Nutrient Index (SNI) ranked from highest to lowest as follows: *Hedysarum scoparium* > *Pinus sylvestris* > *Medicago sativa* > *Amorpha fruticosa* > *Amygdalus pedunculata* > *Artemisia desertorum*. The results indicate that *Hedysarum scoparium* forest has the best soil nutrient status, and among the six vegetation types, *Hedysarum scoparium* is the most suitable vegetation for planting in the Mu Us Sandy Land.

### Full Text

#### Effects of Artificial Sand-Fixing Vegetation on Soil Nutrients in the Mu Us Sandy Land

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## Abstract

To explore the influence patterns of different artificial sand-fixing vegetation types on soil nutrients in the Mu Us Sandy Land, six typical artificial sand-fixing vegetation types were selected as research subjects. The physical and chemical properties of 0-100 cm soil profiles were analyzed, and the soil nutrient index (SNI) for each vegetation restoration model was calculated using principal component analysis. The results showed no significant differences in soil bulk density among the six vegetation types, exhibiting weak variation. Soil organic carbon (SOC) and total nitrogen content were both higher in the surface layer than in deeper layers, while total potassium and phosphorus content showed no significant patterns. The SOC density in the 0-20 cm layer was significantly higher than in other layers, demonstrating obvious surface aggregation. Except for the bare sand control, the SOC cumulative reserves in the 0-100 cm profile of the six vegetation plots could be simulated by a logarithmic function [ $y = a \ln(x) + b$ ] with  $R^2 > 0.96$ . The SNI values, from highest to lowest, were: *Hedysarum scoparium* > *Pinus sylvestris* > *Medicago sativa* > *Amorpha fruticosa* > *Amygdalus pedunculata* > *Artemisia desertorum*. These results indicate that *Hedysarum scoparium* forest has the best soil nutrient status, and among the six vegetation types, *Hedysarum scoparium* is the most suitable species for planting in the Mu Us Sandy Land.

**Keywords:** Mu Us Sandy Land; artificial sand fixation; soil bulk density; soil nutrients; nutrient index

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## 1 Materials and Methods

### 1.1 Study Plots

This study was conducted at the Mu Us Sand Control Afforestation Base of the Shenmu City Ecological Association in Shaanxi Province (109°52'9" E, 38°53'40" N), located on the southern edge of the Mu Us Sandy Land in the transition zone between the sandy land and the Loess Hilly Region. The site has an altitude of approximately 1258 m, a mean annual temperature of 8.5 °C, and annual precipitation of 250-440 mm, with 60-75% concentrated in July-September. The maximum daily precipitation is 141.7 mm, and annual evaporation is about 4-5 times the precipitation. The soil type is primarily aeolian sandy soil, and the main vegetation consists of artificial sand-fixing forests, including *Hedysarum scoparium*, *Amygdalus pedunculata*, *Amorpha fruticosa*, *Medicago sativa*, *Artemisia desertorum*, and *Pinus sylvestris*.

## 1.2 Experimental Design and Sampling

Soil sampling was conducted in July 2016 at the Mu Us Sand Control Afforestation Base (109°52'9" E, 38°53'40" N). Typical plots of *Pinus sylvestris*, *Amygdalus pedunculata*, *Hedysarum scoparium*, *Artemisia desertorum*, *Amorpha fruticosa*, and *Medicago sativa* were selected as study objects, with bare sand land as the control. Each plot was selected on terrain with similar topographic characteristics. After removing the humus layer, soil profile samples were collected using a five-point sampling method at depths of 0–100 cm at 20 cm intervals. Three replicate soil samples were collected from each plot, totaling 126 samples. Visible plant roots, stones, litter, and debris were removed, and samples were air-dried in the laboratory and passed through 0.25 mm and 0.149 mm sieves. Soil bulk density was measured using the ring knife method by excavating 100 cm deep soil profiles and collecting ring knife samples at 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm depths, with three replicates per depth, totaling 105 ring knife samples.

## 1.3 Laboratory Analysis

Soil organic carbon content was determined using the Walkley-Black method, and total nitrogen content was measured by the Kjeldahl method. Total phosphorus was determined by molybdenum-antimony colorimetry, and available phosphorus was measured by the Olsen method. Ammonium nitrogen ( $\text{NH}_4^+$ -N) and nitrate nitrogen ( $\text{NO}_3^-$ -N) were extracted from fresh soil with 2M KCl and analyzed using an Alpkem autoanalyzer.

## 1.4 Calculation of SOC Density and Soil Nutrient Index (SNI)

**1.4.1 Soil Organic Carbon Density** SOC density was calculated using the formula:

$$\text{SOC}_s = \text{SOC} \times \text{BD} \times \left(1 - \frac{C}{100}\right) \times 0.01$$

where  $\text{SOC}_s$  represents soil organic carbon density ( $\text{kg} \cdot \text{m}^{-2}$ ), SOC is soil organic carbon content ( $\text{g} \cdot \text{kg}^{-1}$ ), BD is soil bulk density ( $\text{g} \cdot \text{cm}^{-3}$ ), and C is the percentage of particles  $>2$  mm.

**1.4.2 Soil Nutrient Index (SNI)** A continuous membership function was used to calculate the membership values of each nutrient factor. All nutrient factor data were processed using an ascending distribution function:

$$f(X_i) = \frac{X_i - \min}{\max - \min}$$

where  $f(X_i)$  represents the membership value of each nutrient factor,  $X_i$  is the average value of the nutrient factor in the corresponding soil layer, and min and max represent the minimum and maximum values of the  $i$ th nutrient factor in each soil layer.

The SNI was calculated as:

$$\text{SNI} = \sum_{i=1}^n W_i \times N_i$$

where  $n$  is the number of soil nutrient indicators,  $W_i$  is the weight vector of each nutrient factor, and  $N_i$  is the membership value of each nutrient factor.

## 1.5 Data Analysis

SPSS 22.0 (IBM, Armonk, NY, USA) was used for one-way ANOVA and least significant difference (LSD) tests to compare soil nutrients among the six vegetation types, bare sand, and different soil depths. Principal component analysis was used to analyze the SNI of the six vegetation types.

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## 2 Results

### 2.1 Changes in Soil Bulk Density

Soil bulk density is an important parameter for assessing soil nutrients. Under different artificial sand-fixing vegetation types, soil bulk density varied with depth, ranging from 1.61 to 1.65  $\text{g} \cdot \text{cm}^{-3}$ . Throughout the entire soil profile, *Amygdalus pedunculata* had the lowest soil bulk density compared to the control, but showed no significant differences with increasing depth, remaining around 1.55  $\text{g} \cdot \text{cm}^{-3}$ . The other five vegetation types showed no significant changes in soil bulk density with depth, exhibiting fluctuating but non-significant variations.

All vegetation types reduced soil bulk density and improved sandy soil structure. The surface soil (0–20 cm) had the lowest bulk density in *Medicago sativa* and *Hedysarum scoparium* plots, which increased significantly at 20–40 cm and then remained relatively stable with increasing depth, staying around 1.60  $\text{g} \cdot \text{cm}^{-3}$  for *Medicago sativa* and 1.68  $\text{g} \cdot \text{cm}^{-3}$  for *Hedysarum scoparium*. The coefficients of variation for all six vegetation types showed weak variation, with *Medicago sativa* having the highest variation coefficient, followed by *Hedysarum scoparium*. *Amygdalus pedunculata*, *Pinus sylvestris*, *Amorpha fruticosa*, and *Artemisia desertorum* showed no significant changes in soil bulk density with increasing depth [Figure 1: see original paper]. In the surface layer (0–20 cm), *Medicago sativa* had the lowest soil bulk density, followed by *Hedysarum scoparium* and *Amygdalus pedunculata*, which decreased by 7.9%, 6.9%, and 6.3% compared to the bare sand control, respectively.

### 2.2 Changes in Soil Nutrients

Analysis of soil nutrient changes in different vegetation plots revealed that, according to the national soil nutrient classification standards, soil nutrients in the

Mu Us Sandy Land are at relatively low levels. Although all nutrient indicators were low in the six vegetation plots, they were significantly higher in the surface soil (0–20 cm) than in deeper layers ( $P < 0.05$ ). SOC and total nitrogen content in all vegetation plots were significantly higher than in bare sand ( $P < 0.05$ ), while total phosphorus content showed no significant changes.

SOC and total nitrogen content in all six vegetation plots decreased with increasing soil depth. Significant differences existed among vegetation types in the same soil layer ( $P < 0.05$ ), particularly in the 0–20 cm layer, where *Hedysarum scoparium* had the highest soil nutrient content. Compared to bare sand, SOC and total nitrogen content in the *Hedysarum scoparium* plot increased by 177.6% and 125.1%, respectively. For the entire soil profile, *Hedysarum scoparium* had the highest SOC content, followed by *Amorpha fruticosa* and *Medicago sativa*, which increased SOC by 26.9% compared to the control. All six vegetation types significantly increased SOC content [Figure 2: see original paper].

Phosphorus content in the Mu Us Sandy Land was severely deficient, ranging from 0.16 to 0.35  $\text{g} \cdot \text{kg}^{-1}$ , and showed a decreasing trend with depth. However, in *Pinus sylvestris*, *Artemisia desertorum*, and *Amygdalus pedunculata* plots, total phosphorus content first increased and then decreased with depth. In *Pinus sylvestris* plots, total phosphorus content in the 20–60 cm layer was significantly higher than in the surface layer, while in *Amygdalus pedunculata* plots, the 40 cm layer was significantly higher than the surface layer ( $P < 0.05$ ). Although *Artemisia desertorum* and *Amygdalus pedunculata* plots had relatively high available phosphorus content, *Hedysarum scoparium* plots showed significantly increased available phosphorus content ( $P < 0.05$ ). All soil nutrient indicators showed increasing trends in the 20–80 cm layer, but not significantly.

### 2.3 Changes in Soil Organic Carbon Density

SOC density was significantly higher in the surface layer than in deeper layers ( $P < 0.05$ ). The surface soil (0–20 cm) of *Hedysarum scoparium* plots had the highest SOC density, followed by *Medicago sativa*, *Amorpha fruticosa*, and *Amygdalus pedunculata*, which increased by 157.9%, 136.8%, 105.3%, and 94.7% compared to bare sand, respectively ( $P < 0.05$ ). Although SOC density showed no significant changes across the entire profile for each vegetation type, all vegetation plots showed decreasing trends with increasing depth. Significant differences in SOC density existed among vegetation plots ( $P < 0.05$ ), primarily due to the influence of soil-forming processes and vegetation types. In the 0–40 cm layer, *Hedysarum scoparium* and *Medicago sativa* plots were significantly higher than bare sand ( $P < 0.05$ ).

### 2.4 Changes in Soil Organic Carbon Cumulative Storage

Soil carbon sequestration potential can be evaluated by estimating organic carbon reserves. This study selected the 0–100 cm depth for estimation to facilitate comparison with international research. Analysis of cumulative SOC storage in

different vegetation plots showed that the six vegetation types increased ecosystem carbon pools. Cumulative SOC storage per unit area varied with depth, with *Amygdalus pedunculata* and *Hedysarum scoparium* having the highest storage in the 0–100 cm profile, increasing by 168.5% and 149.3% compared to bare sand, respectively. *Artemisia desertorum* plots had the lowest storage, increasing by only 69.9% compared to bare sand [Figure 3: see original paper].

Changes in cumulative SOC storage with depth could be simulated by logarithmic functions [ $y = a \ln(x) + b$ ] for the six vegetation plots ( $R^2 > 0.96$ ), while bare sand could be simulated by a linear function ( $R^2 > 0.90$ ). This difference occurs because bare sand has no vegetation cover, whereas in vegetation plots, roots and litter decrease with depth, causing SOC storage to change logarithmically.

## 2.5 Changes in Soil Nutrient Index

To comprehensively evaluate soil nutrient quality under different vegetation types, principal component analysis was used to calculate SNI values. All six vegetation types improved the SNI, with *Hedysarum scoparium* having the highest SNI value (0.69), followed by *Pinus sylvestris* (0.59). *Artemisia desertorum* had the lowest SNI (0.28), while other vegetation types showed intermediate values. The ranking of SNI values for the six vegetation types was: *Hedysarum scoparium* > *Pinus sylvestris* > *Medicago sativa* > *Amorpha fruticosa* > *Amygdalus pedunculata* > *Artemisia desertorum*.

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## 3 Discussion

### 3.1 Main Factors Affecting Soil Under Artificial Sand-Fixing Vegetation (Roots, Litter) and Their Effects

Soil bulk density, as a fundamental physical property, is influenced by parent material, climate, and biological disturbance, and significantly affects soil nutrients. The lower bulk density in surface soil (0–20 cm) may be due to denser plant root systems, particularly in *Medicago sativa* and *Hedysarum scoparium* plots where developed root systems reduced soil bulk density compared to the control. Research indicates that *Hedysarum scoparium*, a deciduous shrub, can significantly reduce soil bulk density, thereby effectively improving sandy soil texture.

Among the six vegetation types, *Amygdalus pedunculata* had the lowest soil bulk density due to its well-developed root system and dense branches. Large amounts of humus and litter accumulated in the soil through microbial decomposition, making the soil loose and porous, thus reducing bulk density and improving sandy soil structure. Throughout the soil profile, *Hedysarum scoparium* and *Amorpha fruticosa* had relatively higher bulk density, indicating lower improvement effects, which differs from some previous studies. This discrepancy

may be because *Amygdalus pedunculata* more effectively improves soil structure compared to *Hedysarum scoparium* and *Amorpha fruticosa*.

Soil nutrients are the foundation of vegetation growth, directly affecting plant development. All six vegetation types significantly increased SOC content compared to bare sand because litter accumulation and root decomposition significantly change soil fertility levels. In natural ecosystems, decomposition of surface litter and roots is the primary pathway for SOC input. In this study, SOC content decreased with depth in all vegetation plots, indicating that surface litter accumulation and decomposition, along with root metabolism, positively affect SOC and create obvious surface aggregation.

SOC content depends on the balance between accumulation and decomposition. The pattern of SOC change in the six vegetation plots was generally consistent with total nitrogen but differed from total phosphorus, which showed less obvious surface aggregation. Total nitrogen content was lowest in *Medicago sativa* plots because the sampled plots were only 3 years old (initial growth stage) when nitrogen fixation capacity is low and plant growth consumes substantial soil nutrients. Total phosphorus content was significantly lower in all vegetation plots because phosphorus required for plant growth almost entirely comes from soil, consistent with previous research. Soil phosphorus content is mainly influenced by soil type, land use, physicochemical properties, and climate, with parent material phosphorus content affecting adsorption capacity and forming vertical distribution patterns. In the Mu Us Sandy Land, aeolian sandy soil has low development degree and weak phosphorus adsorption capacity, resulting in irregular phosphorus distribution across the soil profile.

### 3.2 Differences in Soil Effects Among Different Vegetation Types

Many ecosystem studies show that SOC decreases with sampling depth. During degraded land restoration, significant differences exist between upper and lower soil layers. Therefore, when evaluating whether SOC storage shows significant responses among different vegetation plots, soil sampling depth must be considered. Most studies show that vertical SOC changes respond differently to various soil layer combinations. This study simulated cumulative SOC storage changes with depth using logarithmic functions for vegetation plots and linear functions for bare sand, because vegetation plots have decreasing roots and litter with depth while bare sand has no vegetation cover.

Due to the complexity of soil fertility formation mechanisms and different scholarly understandings of soil fertility, evaluation methods and indicators vary. However, comprehensive evaluation of soil nutrient levels has become important for regional ecological construction and soil environmental restoration. This study selected six vegetation types in the Mu Us Sandy Land and used principal component analysis to calculate SNI. The results showed that *Hedysarum scoparium* had the highest SNI, making it the most suitable vegetation for this region, followed by *Pinus sylvestris*, *Amorpha fruticosa*, *Medicago sativa*, *Amyg-*

*dalus pedunculata*, and *Artemisia desertorum*.

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## 4 Conclusion

Soil bulk density showed no significant differences among different vegetation plots in the Mu Us Sandy Land. Soil nutrients varied with vegetation restoration type, with *Hedysarum scoparium* having the highest SOC, total nitrogen, and total phosphorus content, followed by *Pinus sylvestris*, *Amorpha fruticosa*, *Medicago sativa*, and *Amygdalus pedunculata*. The cumulative SOC storage per unit area and SOC density were highest in *Hedysarum scoparium* and *Amygdalus pedunculata* plots. *Artemisia desertorum* had low vegetation coverage, resulting in severe soil erosion and SOC loss, while *Hedysarum scoparium* had dense vegetation, well-developed main and lateral roots, and was beneficial for soil nutrient retention, leading to substantial carbon accumulation.

Compared with other vegetation types, *Hedysarum scoparium* and *Amygdalus pedunculata* had the highest soil nutrient levels due to their well-developed root systems and dense branches. Large amounts of litter and root exudates accumulated in the soil and were continuously decomposed and mineralized by microorganisms as vegetation age increased, resulting in substantial nutrient accumulation and improved soil fertility. In this study, *Hedysarum scoparium* was the most suitable vegetation for the Mu Us Sandy Land, followed by *Pinus sylvestris*, *Amorpha fruticosa*, *Medicago sativa*, *Amygdalus pedunculata*, and *Artemisia desertorum*.

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