Soil Nutrient Characteristics of 30-Year Aerial Seeding Plantation on the Northeastern Margin of the Tengger Desert (Postprint)

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Abstract

To clarify the effects of vegetation restoration on soil nutrient accumulation in the 1992 aerial seeding afforestation area at the northeastern edge of the Tengger Desert. This study takes the Calligonum community and mixed community (Hedysarum + Calligonum) formed in the aerial seeding area as research objects to analyze the variation patterns and accumulation effects of soil nutrients. The results show: (1) Vegetation restoration significantly increased soil nutrient content in the aerial seeding area, with soil organic matter (SOM), total nitrogen (TN), total phosphorus (TP), and total potassium (TK) in the Calligonum community and mixed community increasing by 60%–105%, 123%–161%, 129%-149%, and 145%-261%, respectively, with the increase in the Calligonum community being significantly higher than that in the mixed community and bare sand control plot (CK) ($P < 0.05$). Nutrient vertical distribution showed a surface aggregation effect, with content in the 0–10 cm soil layer being significantly higher than that in the 150–200 cm layer. (2) Both communities showed positive effects on nutrient accumulation in the 0–200 cm soil layer, with the effects decreasing with increasing depth ($P < 0.05$); the mean positive effect value of the Calligonum community (0.39) was significantly higher than that of the mixed community (0.29). (3) The soil nutrient recovery indices of the Calligonum community and mixed community were 62.19% and 51.63%, respectively. The study indicates that 30 years after aerial seeding afforestation at the northeastern edge of the Tengger Desert, soil nutrients have been significantly improved, with the Calligonum community showing slightly better promotion of nutrient accumulation than the mixed community, which can provide a theoretical basis for artificial sand-fixing vegetation restoration and stable maintenance in arid regions.

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Full Text

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Keywords: aerial seeding afforestation; vegetation restoration; relative interaction strength; nutrient accumulation; Tengger Desert

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Aerial seeding afforestation is a crucial measure for establishing artificial sand-fixing vegetation systems in arid sandy regions. Vegetation restoration improves soil environments by promoting microbial activity through litter input and root secretions [1-3], while improved soil conditions provide positive feedback for plant growth [4]. Soil nutrients reflect soil characteristics and dynamic changes, serving as important indicators for assessing soil status and ecological functions [5-6]. They play a dominant role in organic matter decomposition and transformation, influencing ecosystem material cycling and energy flow [7], and are affected by climate, soil texture, and vegetation type [8]. Therefore, accurately understanding soil nutrient dynamics in arid desert regions facilitates more effective ecological restoration and management.

In arid desert areas, increasing aerial seeding vegetation age leads to more litter and root secretions, which promote microbial proliferation and significantly elevate nitrogen, phosphorus, potassium, and organic matter content in aeolian sandy soils, particularly enriching the surface layer [9-10]. Jiang et al. [11] reported that *Caragana microphylla* restoration notably improved soil nutrients in Horqin sandy lands. Chen et al. [12] found that surface total nitrogen content was higher than deeper layers in artificial sand-fixing vegetation of the Mu Us Sandy Land, while total potassium showed no significant difference. Zhao et al. [13] observed that soil organic matter increased by 31.4% after vegetation restoration in aerial seeding sand-fixing forests in Wushen Banner, with significant increases in total nitrogen and phosphorus that gradually decreased from the surface downward. Liu et al. [14] demonstrated that vegetation restoration effectively improved soil structure and increased organic matter and total nitrogen in the Kubuqi Desert. Shi et al. [15] showed that psammophytic vegetation restoration promoted soil organic matter and nitrogen accumulation in the Tengger Desert margin. These findings indicate that soil nutrients improve to varying degrees with artificial vegetation restoration across different arid regions, though differences exist in nutrient accumulation among various aerial seeding plantations.

Since the 1990s, aerial seeding afforestation in the northeastern margin of the Tengger Desert has significantly increased vegetation coverage, forming sand-fixing communities dominated by *Calligonum mongolicum*, *Hedysarum scoparium*, and *Artemisia desertorum* [16-17]. However, the effects of long-term vegetation restoration on deep soil nutrients remain unclear. This study systematically analyzed 30-year soil nutrient dynamics in aerial seeding areas using *C. mongolicum* and mixed (*H. scoparium* + *C. mongolicum*) communities to reveal long-term nutrient accumulation effects and provide scientific guidance for soil conservation in arid regions.

1.1 Study Area Overview

The study area is located in an aerial seeding shrubland forest formed since 1992 in the northeastern margin of the Tengger Desert [Figure 1: see original paper], within Alxa Left Banner in western Inner Mongolia (39°11 -39°18 N, 104°53 - 104°57 E). This typical mid-temperate arid desert region features a temperate continental climate with mean annual precipitation of 123.33 mm, concentrated in July–September (accounting for ~70% of annual rainfall). The soil is primarily non-zonal aeolian sandy soil. Dominant plants include *H. scoparium*, *C. mongolicum*, and *A. desertorum*, with additional native species such as *Zygophyllum xanthoxylum*, *Agriophyllum squarrosum*, *Psammochloa villosa*, and *Oxytropis aciphylla*.

1.2.1 Plot Establishment

Three plant community types were selected: *C. mongolicum* community, mixed community (*H. scoparium* + *C. mongolicum*), and bare sand control (CK), with three replicate plots each. Fieldwork was conducted in July 2022. Similar typical dunes were selected in each plot type, and three subplots were established at three slope positions (base, middle, and top of windward and leeward slopes) as basic units for soil nutrient studies. In each plot, 20 m × 20 m shrub quadrats were set up at different slope positions, with 1 m × 1 m herb quadrats established using five-point sampling within each shrub quadrat for plant community surveys .

1.2.2 Soil Sample Collection and Analysis

Standard plants were selected as soil sampling points in the three observation plots: three *C. mongolicum* plants in the *C. mongolicum* plot, three each of *H. scoparium* and *C. mongolicum* in the mixed community plot, and unvegetated areas in the bare sand plot. Soil profiles 200 cm deep were excavated at three slope positions below each standard plant and in inter-plant spaces, totaling 27 profiles. Each profile was sampled at seven depths: 0–10 cm, 10–20 cm, 20–

30 cm, 30-60 cm, 60-100 cm, 100-150 cm, and 150-200 cm. Soils from the *C. mongolicum* and bare sand plots were mixed uniformly by slope position and depth. Mixed community soils were first mixed separately for each species by slope position and depth, then combined uniformly by depth. Samples were air-dried, impurities removed, and reduced using the quartering method. Soil organic matter (SOM), total nitrogen (TN), total phosphorus (TP), and total potassium (TK) were measured following standard methods in *Soil Agrochemical Analysis* [18].

1.2.3 Data Analysis

(1) Soil nutrient accumulation calculation
Relative Interaction Intensity (RII) was used to quantify community effects on soil nutrients [19]. RII ranges from -1 to 1, where RII > 0 indicates nutrient increase by *C. mongolicum* or mixed communities, RII < 0 indicates decrease, and larger absolute values indicate stronger effects [20]:

$$RII = \frac{X_n - X_i}{X_n + X_i}$$

where X_n is the soil nutrient value in plant communities and X_i is the value in bare sand at corresponding depths.

(2) Soil nutrient recovery index calculation
The Nutrient Recovery Index (NRI) quantified vegetation restoration effects [21]:

$$NRI = \frac{1}{n}\sum_{i=1}^{n}\frac{X_i - X_i'}{X_i'} \times 100\%$$

where X_i and X_i' represent nutrient values in the ith soil layer for plant communities and bare sand, respectively.

2.1 Soil Nutrient Characteristics of Different Plant Communities

After 30 years of restoration, soil nutrients improved across all community types [Figure 2: see original paper]. SOM, TN, TP, and TK in the 0-200 cm layer differed significantly between the *C. mongolicum* and mixed communities ($P < 0.05$). Nutrient content in the 0-10 cm layer was significantly higher than in the 150-200 cm layer, demonstrating pronounced surface accumulation. Specifically, SOM, TN, TP, and TK in the 0-10 cm layer increased by 0.220-0.512 $g \cdot kg^{-1}$, 0.011-0.026 $g \cdot kg^{-1}$, 0.025-0.138 $g \cdot kg^{-1}$, and 0.966-5.000 $g \cdot kg^{-1}$, respectively. Nutrients decreased significantly with depth ($P < 0.05$). Across all layers, nutrients followed the pattern: *C. mongolicum* > mixed community > bare sand ($P < 0.05$).

2.2 Soil Nutrient Accumulation in Different Plant Communities

Nutrient accumulation decreased with soil depth in both communities [Figure 3: see original paper]. Both showed significant positive effects at all depths ($P < 0.05$), with RII values of 0.15-0.33 for *C. mongolicum* and 0.28-0.46 for the mixed community. Overall, both communities had significant positive effects in the 0-200 cm layer ($P < 0.05$), but the mean effect was stronger for *C. mongolicum* (0.39) than the mixed community (0.29). Positive effects declined with depth ($P < 0.05$).

2.3 Soil Nutrient Recovery Index Characteristics

The NRI improved in both communities (Tables 2 and 3). The *C. mongolicum* community showed a 62.19% increase over bare sand, while the mixed community increased by 51.63%. The NRI of *C. mongolicum* was 1.2 times that of the mixed community, indicating its superior role in nutrient recovery ($P < 0.05$). Surface soil recovery was significantly greater than deep soil ($P < 0.05$), with effects weakening with depth. The *C. mongolicum* community NRI was 145%-261% higher in the 0-10 cm layer than in the 150-200 cm layer, compared to 123%-161% for the mixed community. Recovery effects decreased consistently with depth.

3 Discussion

Soil nutrient accumulation rates are influenced by plant type, density, and soil texture [22]. After 30 years of restoration, SOM, TN, TP, and TK increased significantly compared to bare sand, especially in the 0-10 cm layer, consistent with findings from the Mu Us Sandy Land [23]. SOM and TN increased by 700.24% and 254.55% in the surface layer, respectively, with diminishing effects at depth. Phosphorus and potassium are critical but often limited nutrients in desert ecosystems. Aerial seeding promotes their release through improved soil properties, though recovery remains in early stages with low overall fertility due to loose soil structure, poor water retention, strong alkalinity (pH 8.46-8.79), and arid climate with high evaporation [24].

The NRI reflects restoration effectiveness on degraded soils [25]. Values of 62.19% for *C. mongolicum* and 51.63% for the mixed community demonstrate significant positive impacts ($P < 0.05$), consistent with studies in Jilantai [26] and Kubuqi [27]. Aerial seeding enhances water infiltration, promotes root growth, and improves soil structure. Root exudates alter soil chemistry, facilitating nutrient release and transformation [28]. These mechanisms increase biodiversity and ecosystem resilience, forming complex ecological networks that enhance self-regulation.

Aerial seeding in the northeastern Tengger Desert margin significantly improved soil nutrient accumulation and overall fertility, supporting ecological restoration. However, soils remain in recovery with low nutrient levels. The study highlights the importance of appropriate species selection and community configuration for accelerating nutrient recovery in arid desert environments, providing crucial guidance for future restoration and soil management.

4 Conclusions

Based on soil nutrient studies in different plant communities of the aerial seeding area:

1. After 30 years of restoration, SOM, TN, TP, and TK increased significantly, with *C. mongolicum* showing the greatest improvement.
2. Both *C. mongolicum* and mixed communities significantly promoted nutrient accumulation, with *C. mongolicum* effects (0.39) exceeding those of the mixed community (0.29).
3. Surface soil (0–30 cm) showed the most significant improvement. NRI values were 62.19% and 51.63% for the two community types, respectively.

References

[1] Zhang Suqiong, Yan Wangui. Problems and control measures of grassland ecological environment in western China[J]. *Acta Prataculturala Sinica*, 2006, 15(5): 11-18.

[2] Wang Tao, Meng Zhongju, Dang Xiaohong, et al. Soil nutrient characteristics of typical shelter forests in the Kubuqi Desert[J]. *Journal of Soil and Water Conservation*, 2022, 36(1): 325-331.

[3] Chen Meijun, Duan Zengmiao. Research status and prospect of soil quality standards in China[J]. *Acta Pedologica Sinica*, 2011, 48(5): 1059-1071.

[4] Yang Yuting, Shi Yulin, Li Zhangang, et al. Characteristics of understory herb communities and their relationships with stand structure and soil nutrients in Three North shelter forests in northern Shaanxi[J]. *Acta Ecologica Sinica*, 2020, 40(18): 6542-6551.

[5] Jiang Shu. Suggestions on the development of returning farmland to forest and grassland in Western China[J]. *Acta Agrestia Sinica*, 2003, 11(1): 10-14.

[6] Jiang Deming, Cao Chengyou, Li Xuehua, et al. Vegetation restoration and its effects on soil improvement in Horqin Sandy Land[J]. *Ecology and Environmental Sciences*, 2008, 17(3): 1135-1139.

[7] Chen Wen, Yang Jingjing, Yuan Yuan, et al. Effects of artificial sand fixing vegetation on soil nutrients in Mu Us Sandy Land[J]. *Arid Zone Research*, 2020, 37(6): 1447-1456.

[8] Zhao Chunguang, Yan Deren, Xue Yingying. Features of vegetation community and changes of soil physical and chemical property in the sand fixation forest

by aerial seeding[J]. *Journal of Inner Mongolia Forestry Science and Technology*, 2007, 33(4): 4-6.

[9] Liu Yuan, Li Xiaojing, Duan Yuxi, et al. Effects of vegetation restoration on soil stoichiometry in the eastern Hobq Desert[J]. *Arid Zone Research*, 2022, 39(3): 924-932.

[10] Shi Ming, Wang Rui, Sun Quan, et al. Vegetation restoration and soil nutrient changes in edge of Tengger Desert[J]. *Bulletin of Soil and Water Conservation*, 2013, 33(6): 107-111.

[11] Man Duoqing, Wu Chunrong, Xu Xianying, et al. Monthly changing characteristics on desert vegetation coverage and eco restoration in Southeast fringe area of Tengger Desert[J]. *Journal of Desert Research*, 2005, 25(1): 142-146.

[12] Qi Jing, Jiao Liang, Chen Ke, et al. Drought wet variation of Changling Mountain in Southeast of Tengger Desert since 1872[J]. *Arid Zone Research*, 2021, 38(5): 1318-1326.

[13] Bao Shidan. *Soil Agrochemical Analysis*[M]. 3rd ed. Beijing: China Agricultural Press, 2000.

[14] Armas C, Ordiales R, Pugnaire F I. Measuring plant interactions: A new comparative index[J]. *Ecology*, 2004, 85(10): 2682-2686.

[15] Luo Weicheng, Zhao Wenzhi, Ren Heng, et al. Nebkha morphological characteristics and soil nutrition content in three regions with different climates in North China[J]. *Journal of Desert Research*, 2021, 41(2): 191-199.

[16] Bruno J F, Stachowicz J J, Bertness M D. Inclusion of facilitation into ecological theory[J]. *Trends in Ecology & Evolution*, 2003, 18(3): 119-125.

[17] Goldberg D E, Rajaniemi T, Gurevitch J, et al. Empirical approaches to quantifying interaction intensity: Competition and facilitation along productivity gradients[J]. *Ecology*, 1999, 80(4): 1118-1131.

[18] Holzapfel C, Mahall B E. Bidirectional facilitation and interference between shrubs and annuals in the Mojave Desert[J]. *Ecology*, 1999, 80(5): 1747-1761.

[19] Dong Lili, Zheng Fenli. Effects of land use and vegetation types on soil quality in the loess gully region of China[J]. *Journal of Lanzhou University (Natural Sciences)*, 2010, 46(2): 39-44.

[20] Xiong Yingnan, Feng Tianjiao, Wang Ping, et al. Effects of long term artificial forest restoration on soil moisture and nutrient characteristics in the loess area of Western Shanxi Province, China[J]. *Journal of Soil and Water Conservation*, 2022, 36(2): 228-237, 246.

[21] Dong Zhengwu, Umut Halik, Li Shengyu, et al. Soil stoichiometric characteristics of Tamarix cones in the southwest margin of Gurbantunggut Desert[J]. *Acta Ecologica Sinica*, 2020, 40(20): 7389-7400.

[22] Qian Zhou, Yu Yuanchun, Yu Xiaopeng, et al. Changes of vegetation characteristics and soil properties in Mu Us Sandy Land by aerial seeding afforestation[J]. *Journal of Central South University of Forestry and Technology*, 2014, 34(4): 102-107.

[23] Gao Miao. Study on Plant Community Characteristics and Soil Physical and Chemical Properties of Aerial Seeding Afforestation Area in the Northeastern Margin of Tengger Desert[D]. Hohhot: Inner Mongolia Agricultural University, 2023.

[24] Wei Yajuan, Liu Meiying, Xie Yunhu, et al. Characteristics of soil nutrient accumulation after 38 years of the Jilantai Salt Lake protection system[J]. *Arid Zone Research*, 2023, 40(5): 747-755.

[25] Wang Bo, Duan Yuxi, Wang Weifeng, et al. Carbon and nitrogen storage and distribution patterns of desert ecosystems at different vegetation restoration stages in the eastern Hobq Desert[J]. *Acta Ecologica Sinica*, 2019, 39(7): 2470-2480.

[26] Jin Zhengzhong, Lei Jiaqiang, Xu Xinwen, et al. Change and evaluation of soil fertility quality in Tarim Desert Highway Shelterbelt[J]. *Chinese Science Bulletin*, 2008, 53(S2): 112-122.

[27] Zeng Quanchao, Li Xin, Dong Yanghong, et al. Ecological stoichiometry characteristics and physical chemical properties of soils at different latitudes on the Loess Plateau[J]. *Journal of Natural Resources*, 2015, 30(5): 870-879.

[28] Zhou Ping, Liu Guobin, Hou Xilu. Study on vegetation and soil nutrient characters of *Artemisia sacrorum* communities in hilly gully region of the Loess Plateau[J]. *Acta Prataculturae Sinica*, 2008, 17(2): 9-18.

Note: Figure translations are in progress. See original paper for figures.