Postprint of Soil Nutrient and Stoichiometric Characteristics of Russian Olive Shelterbelt in the Kubuqi Desert

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Abstract

To investigate the soil nutrient and stoichiometric characteristics of Elaeagnus angustifolia shelterbelts on the northeastern edge of the Kubuqi Desert, and to provide a theoretical basis for the sustainable utilization of desert shelterbelts, we selected 30 m × 30 m representative sample plots in Elaeagnus angustifolia shelterbelts of different stand ages (3 a, 9 a, 15 a), collected stratified samples from the 0–50 cm soil profile, and analyzed soil nutrient elements and stoichiometric characteristics in Elaeagnus angustifolia forests of different stand ages. The results showed that: pH in different soil layers of Elaeagnus angustifolia shelterbelts of different stand ages generally fluctuated little. Nutrient elements in Elaeagnus angustifolia forests were significantly affected by stand age and soil depth, showing a significant increase in nutrient content with stand age and a vertical decrease along the soil profile, demonstrating a certain surface accumulation phenomenon. Among them, stand age had a greater influence on soil available potassium, total phosphorus, and total potassium, with increases of 152.2%, 58.0%, and 69.5%, respectively, in the 15 a stand age compared with bare sand land. The C:N, C:P, and N:P ratios in the 0–50 cm soil layer of Elaeagnus angustifolia shelterbelts of different stand ages were 9.25–18.99, 4.78–5.96, and 0.31–0.63, respectively, and all were subject to the dual effects of stand age and soil depth. Comprehensive analysis of stoichiometric characteristics revealed that Elaeagnus angustifolia shelterbelts on the northeastern edge of the Kubuqi Desert had significant ameliorative effects on aeolian sandy soil, and that forest soil nutrient status was mainly influenced by C and N elements, with soil N mineralization capacity being relatively weak and nitrogen deficiency present; therefore, nitrogen fertilizer should be appropriately applied in subsequent management.

Full Text

Abstract

To investigate soil nutrient and stoichiometric characteristics of *Elaeagnus angustifolia* shelterbelts in the northeastern margin of the Hobq Desert and provide a theoretical basis for sustainable utilization of desert shelterbelts, we analyzed soil nutrient elements and stoichiometric characteristics across different forest ages (3, 9, and 15 years) using 30 m × 30 m representative sample plots. Soil samples were collected from stratified layers of 0–50 cm soil profiles. The results showed that soil pH fluctuated little across different soil layers in shelterbelts of varying ages, while nutrient elements were significantly affected by both forest age and soil depth. Nutrient content increased significantly with forest age and decreased vertically along the soil profile, demonstrating a clear surface accumulation phenomenon. Forest age had particularly strong effects on soil available potassium, total phosphorus, and total potassium, which at 15 years increased by 152.2%, 58.0%, and 69.5%, respectively, compared with bare sandy land. The C:N, C:P, and N:P ratios in the 0–50 cm soil layer ranged from 9.25–18.99, 4.78–5.96, and 0.31-0.63, respectively, across different forest ages, and were influenced by the dual effects of forest age and soil depth. Comprehensive stoichiometric analysis revealed that *E. angustifolia* shelterbelts remarkably improved aeolian sandy soil in the northeastern Hobq Desert margin. Soil nutrient status was primarily affected by carbon and nitrogen elements, with weak nitrogen mineralization capacity and nitrogen deficiency. Therefore, nitrogen fertilizer should be appropriately applied in future management practices.

Keywords: soil nutrient; stoichiometric characteristics; *Elaeagnus angustifolia* shelterbelt; forest age; Hobq Desert

1.1 Study Area Description

The northeastern margin of the Hobq Desert is located in Hanggin Banner, Ordos City, Inner Mongolia, with geographical coordinates of 107°10 -111°45 E and 37°20 -39°50 N. The study area features a mid-temperate continental monsoon climate with low rainfall intensity, an average annual precipitation of approximately 260 mm, and a high-incidence period for drought. The region experiences large diurnal temperature variations, with an average annual temperature of 5–8°C. Spring (March–May) is the high-incidence period for sandstorm weather, with an average wind speed of 3.2 $m \cdot s^{-1}$. The study area is dominated by fixed, semi-fixed, and shifting sand dunes. Vegetation is diverse, with main herbaceous species including *Artemisia desertorum*, *Psammochloa villosa*, and *Elymus dahuricus*, and tree/shrub species including *E. angustifolia*, *Caragana microphylla*, and *Pinus sylvestris*.

1.2.1 Sample Plot Survey

In early August, we selected *E. angustifolia* shelterbelts of different establishment years (3, 9, and 15 years) as sample plots in the northeastern margin of the Hobq Desert. We surveyed tree height, crown width, and spacing within each plot, and calculated average tree height and crown width for different forest ages. Based on these results, we selected representative 30 m × 30 m standard plots for each forest age, with bare sandy land serving as the control (CK). Basic characteristics of the study plots are shown in Table 1.

1.2.2 Soil Sample Collection and Analysis

Soil Sample Collection: Soil samples were collected in mid-August. Within each selected standard plot, three soil sampling points were randomly arranged in a "品" shape. At each point, a 0–50 cm soil vertical profile was excavated with 10 cm intervals (0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, and 40–50 cm layers). Each layer was sampled using a ring knife. Soil samples were air-dried in a ventilated laboratory, plant roots and debris were removed, and samples were sieved through a 0.15 mm mesh for determination of soil available and total nutrients.

Soil Nutrient Determination: Total nitrogen (TN) was determined by the Kjeldahl method; total phosphorus (TP) by molybdenum-antimony anti-colorimetry after NaOH fusion; total potassium (TK) by flame photometry after NaOH fusion; alkali-hydrolyzable nitrogen (AN) by the alkali diffusion method; available phosphorus (AP) by the Olsen method; available potassium (AK) by ammonium acetate extraction-flame photometry; and organic matter (SOM) by the potassium dichromate external heating method.

1.3 Data Processing and Analysis

Experimental data were screened, organized, and calculated in Excel 2019, then analyzed using SPSS 23.0. One-way ANOVA was used to compare differences in soil nutrient elements and stoichiometric ratios among different forest ages, with significance set at $P < 0.05$.

2 Results and Analysis

2.1 Soil pH Distribution Characteristics

Soil pH in *E. angustifolia* shelterbelts of different ages fluctuated between 7.90–8.97 across soil layers, indicating alkaline soil conditions. Overall, pH showed an upward trend with increasing forest age, with significant differences among forest ages in the 0–40 cm layer ($P < 0.05$). When the establishment period reached 15 years, soil pH in the 40–50 cm layer was significantly higher than in other layers, and pH in each soil layer was significantly higher than in the surface layer (0–10 cm) of bare sandy land.

2.2 Soil Nutrient Distribution Characteristics

2.2.1 Total Nitrogen (TN) and Alkali-Hydrolyzable Nitrogen (AN) Soil TN content in *E. angustifolia* shelterbelts of different ages showed an overall upward trend with increasing forest age and a vertical decreasing pattern from top to bottom along the soil profile. The 15-year shelterbelt showed significantly higher TN content than the 9-year, 3-year, and bare sandy land (CK), with significant differences among forest ages ($P < 0.05$). The fluctuation amplitude was greatest in the 0–10 cm layer, where TN increased by 62.4% compared with bare sandy land (CK). Soil AN content showed more stable changes, with a particularly obvious decreasing trend along the soil profile and significant differences among forest ages in the 0–10 cm layer ($P < 0.05$). *E. angustifolia* shelterbelt soil AN content was significantly higher than CK, with increases of 274.4% and 77.8% in the 0–10 cm and 10–20 cm layers, respectively, at 15 years compared with CK. Similarly, the 9-year shelterbelt showed increases of 292.0% and 144.4% in these layers. In summary, soil TN and AN contents generally increased with forest age.

2.2.2 Total Phosphorus (TP) and Available Phosphorus (AP) With increasing forest age, soil TP content in each layer showed an overall upward trend, with the 15-year shelterbelt showing significantly higher TP content than the 9-year, 3-year, and CK in the 0–10 cm layer ($P < 0.05$). Soil TP content decreased vertically along the soil profile from top to bottom. The distribution pattern of soil AP content with forest age and soil layer was similar to that of TP, though the variation amplitude was smaller and showed no significant differences among different forest ages ($P > 0.05$). Within each soil layer of different forest ages, AP content in the 0–10 cm and 10–20 cm layers was significantly higher than in the 10–30 cm layer ($P < 0.05$). With increasing soil depth, the decreasing trend of AP content was more obvious, with surface soil (0–10 cm) being significantly higher than other layers.

2.2.3 Total Potassium (TK) and Available Potassium (AK) Overall, soil TK content in each layer increased substantially with forest age and decreased from top to bottom along the vertical soil profile. The 15-year shelterbelt showed significantly higher TK content than CK across all soil layers, with increases of 78.3%, 69.3%, 60.3%, and 61.4% in the 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm layers, respectively, relative to CK. The fluctuation pattern of AK content with forest age and soil layer was similar to that of TK. The 15-year shelterbelt showed significantly higher AK content than CK, with the 0–10 cm layer being significantly higher than other layers ($P < 0.05$).

2.2.4 Soil Organic Matter (SOM) The 15-year shelterbelt showed significantly higher SOM content than the 9-year, 3-year, and CK ($P < 0.05$), with significant differences among soil layers ($P < 0.05$). Specifically, SOM content in the 0–10 cm layer of the 15-year shelterbelt increased by 78.1% compared with CK, while the 9-year shelterbelt showed increases of 491.1% and 37.69% in the 0–10 cm and 30–40 cm layers, respectively, compared with CK. The 3-year shelterbelt showed increases of 71.98% in the 0–10 cm layer relative to CK.

2.3 Soil Stoichiometric Characteristics

2.3.1 Soil C:N Ratio The soil C:N ratio in *E. angustifolia* shelterbelts of different ages ranged from 9.25–18.99 in the 0–50 cm layer. The ratio showed significant differences among forest ages within the same soil layer ($P < 0.05$) and a sharply decreasing trend with increasing forest age. The 15-year shelterbelt showed significantly lower C:N ratios than the 3-year shelterbelt across all soil layers, with decreases of 47.6% and 131.0% in the 0–10 cm and 40–50 cm layers, respectively. The C:N ratio showed an overall increasing trend with soil depth.

2.3.2 Soil C:P Ratio The soil C:P ratio in *E. angustifolia* shelterbelts of different ages ranged from 4.78–5.96 in the 0–50 cm layer, showing an upward trend with increasing forest age. The 15-year shelterbelt showed significantly higher C:P ratios than the 3-year and 9-year shelterbelts in the 0–10 cm layer ($P < 0.05$). The C:P ratio showed a decreasing pattern along the vertical soil profile. With increasing forest age, the C:P ratio in the 10–50 cm layers increased by 194.0% and 123.3% compared with the 0–10 cm layer, indicating that forest age had a greater impact on surface soil C:P ratios ($P < 0.05$).

2.3.3 Soil N:P Ratio The soil N:P ratio in *E. angustifolia* shelterbelts of different ages ranged from 0.31–0.63 in the 0–50 cm layer, showing a substantial increase with forest age and significant differences among forest ages ($P < 0.05$). The N:P ratio showed small fluctuations with forest age in the 0–20 cm layer, presenting a trend of first decreasing then increasing. With increasing soil depth, the N:P ratio gradually decreased. The 15-year shelterbelt showed significantly higher N:P ratios than CK across all soil layers ($P < 0.05$).

3 Discussion

3.1 Effects of Forest Age on Soil pH and Nutrients

Elaeagnus angustifolia is an excellent water and soil conservation tree species in northern China with strong environmental tolerance, and its growth is hardly restricted by alkaline soil conditions. In this study, soil pH in shelterbelts of different ages showed a slow upward trend with increasing forest age (ranging from 7.90–8.97), possibly due to increased water demand during the vigorous growth period of *E. angustifolia*, leading to accumulation of soil salt ions. Soil nutrients accumulate during vegetation construction, development, and succession processes. Through microbial participation, litter and animal residues undergo humification and mineralization, decomposing into organic matter and available nutrients. After establishing *E. angustifolia* shelterbelts in the northeastern margin of the Hobq Desert, soil TN, TP, TK, AN, AP, AK, and SOM contents all increased significantly, with significant differences among forest ages within the same soil layer. Among these, soil TN, TP, and TK contents increased substantially with forest age, with the most significant changes observed at 15 years compared with bare sandy land. The northeastern margin of the Hobq Desert has superior moisture conditions compared with the central and western regions, and the primary management goal is preventing southward, northward, and eastward sand invasion. After establishing *E. angustifolia* shelterbelts, two processes occurred simultaneously: (1) as tree age increased, the crown enhanced wind-sand interception, surface litter cover reduced near-surface wind speed, alleviated surface wind erosion, and vegetation residues conserved water, supplementing soil moisture while effectively stabilizing shifting sand; and (2) young shelterbelts (3 years) had smaller morphology, high nutrient demand, and lower soil nutrient content, but as tree age increased, litter interception strengthened, understory herbaceous vegetation gradually recovered, litter return increased, and biological cycling intensified, promoting litter transformation and decomposition and creating favorable conditions for soil nutrient accumulation. These findings align with Zhang et al. Soil nutrient content in shelterbelts of different ages generally decreased with soil depth, with surface layer (0–10 cm) nutrient content being significantly higher than deep layers (40–50 cm), showing obvious surface accumulation. This pattern is similar to results reported by Zhang et al. and Dong et al., revealing that *E. angustifolia* shelterbelts can effectively promote restoration of aeolian sandy soil fertility. With increasing forest age, soil nutrient content fluctuated substantially in the 0–10 cm layer but slowed significantly in the 10–50 cm layers. In arid desert regions, soil nutrient accumulation is influenced by rainfall, soil texture, topography, and vegetation type. The establishment of *E. angustifolia* shelterbelts changed the local ecological environment; as forest age increased, surface litter accumulation and intense microbial activity created favorable conditions for organic matter formation. However, microbial respiration rate decreases with depth, limiting humification to the surface layer and having minimal impact on deep soil. Soil nitrogen mainly originates from organic matter decomposition, while potassium surface accumulation may be related to soil evaporation and root structure.

3.2 Effects of Forest Age on Soil Stoichiometric Characteristics

The soil C:N ratio serves as an indicator of soil quality, reflecting organic matter decomposition rate and nitrogen mineralization rate, thereby affecting shelterbelt growth. In this study, the C:N ratio in *E. angustifolia* shelterbelts (9.25–18.99) was lower than the national average (10–12), indicating nitrogen deficiency, limited microbial physiological activity, slowed organic matter transformation, and insufficient nitrogen mineralization capacity, which is unfavorable for plant nutrient absorption. This differs from results reported by Yang et al., likely due to comprehensive effects of climate, soil type, and vegetation. The soil C:P ratio can indicate microbial nutrient adsorption capacity; smaller ratios are more beneficial for microbial phosphorus release. The C:P ratio in this study (4.78–5.96) was far lower than the national average (52–78), indicating that as forest age increased, the soil microbial capacity to release phosphorus was relatively strong, which is favorable for soil available phosphorus. The soil N:P ratio serves as an indicator for determining vegetation nutrient limitation, with lower ratios indicating greater nitrogen limitation. The N:P ratio in this study (0.31–0.63) was significantly lower than the national average (5–6), indicating that *E. angustifolia* shelterbelts in this region are primarily limited by nitrogen. The N:P ratio showed a vertical decreasing trend, reflecting that nitrogen limitation along the soil profile is greater than phosphorus limitation. This occurs because soil nitrogen mainly originates from organic matter decomposition, while phosphorus can also be supplemented through parent rock weathering. Overall, *E. angustifolia* shelterbelts in the northeastern Hobq Desert margin are primarily limited by nitrogen, and nitrogen fertilizer should be applied to supplement soil nitrogen during management.

4 Conclusions

This study analyzed soil nutrients and stoichiometric characteristics of *E. angustifolia* shelterbelts with three different forest ages (3, 9, and 15 years) in the northeastern margin of the Hobq Desert, yielding the following main conclusions:

1. Soil pH in *E. angustifolia* shelterbelts of different ages ranged from 7.90–8.97, indicating alkaline conditions. Forest age had significant effects on pH across soil layers, with pH increasing with forest age.

2. Soil nutrients in *E. angustifolia* shelterbelts increased with forest age and decreased with soil depth. Forest age had more significant effects on TN, TP, and TK than on other nutrient indicators, with soil nutrients mainly concentrated in the 0–10 cm layer. As establishment duration extended, the soil environment improved significantly.

3. Forest age and soil depth significantly affected soil C:N, C:P, and N:P ratios. The soil N:P ratio (0.31–0.63) indicated that nitrogen is the primary limiting factor for *E. angustifolia* shelterbelt growth in the northeastern Hobq Desert margin. Nitrogen deficiency is a key factor affecting nutrient cycling in these shelterbelts. We recommend supplementing nitrogen content during shelterbelt management to improve soil fertility and provide favorable soil conditions for *E. angustifolia* growth.

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