

Postprint: Response of Soil Physicochemical Properties of *Pinus sylvestris* var. *mongolica* Sand-Fixation Forests to Stand Density

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Abstract

To investigate the effects of stand density on soil physicochemical properties in Mongolian pine (*Pinus sylvestris* var. *mongolica*) artificial sand-fixation forests, middle-aged Mongolian pine stands (stand age 23–27 years) with densities of 625 (P1), 775 (P2), 1025 (P3), 1175 (P4), and 1250 (P5) trees · hm² were selected in the Zhanggutai region as study subjects. Soil physicochemical properties were analyzed by layer for Mongolian pine forest soils at depths of 0–100 cm, divided into the following layers: 0–10, 10–20, 20–40, 40–60, 60–80, and 80–100 cm. The results showed that total nitrogen in the 0–10 cm soil layer and soil bulk density in the 20–40 cm layer exhibited an increasing trend with increasing density, with P5 being significantly higher than P1 ($P < 0.05$); total potassium in the 0–80 cm soil layer and pH in the 0–60 cm layer first increased and then decreased with increasing density, peaking in P3, and total potassium in the P3 plot was significantly higher than that in P1 in the 10–60 cm layer ($P < 0.05$); pH in the 0–40 cm layer was significantly higher than in other plots ($P < 0.05$); total phosphorus in the 0–10 cm layer decreased with increasing density, with P1 being significantly higher than P3–P5 ($P < 0.05$); available potassium in P4 or P5 plots was significantly higher than in P1 and P2 plots in the 0–40 cm layer ($P < 0.05$), and significantly higher than in P3 plots in the 40–100 cm layer ($P < 0.05$); soil porosity in P2–P4 plots was lower than in P1 and P5 plots in the 40–100 cm layer. Considering the comprehensive effects of stand density on soil physicochemical properties in middle-aged Mongolian pine forests, the reasonable stand density for Mongolian pine forests in the Zhanggutai region is 1025–1175 trees · hm². Silvicultural management measures such as thinning can be adopted to adjust stand density and ensure favorable soil conditions for the growth of Mongolian pine sand-fixation forests.

Full Text

Response of Soil Physicochemical Properties under Sand-Fixation Forest of *Pinus sylvestris* var. *mongolica* to Stand Density

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Abstract:

This study analyzed the effects of stand density on soil physicochemical properties in 23–27-year-old *Pinus sylvestris* var. *mongolica* plantations in the Zhanggutai region. Five stand densities were investigated: 625 (P1), 775 (P2), 1025 (P3), 1175 (P4), and 1250 (P5) plants · hm². Soil samples were collected from six depth intervals (0–10, 10–20, 20–40, 40–60, 60–80, and 80–100 cm) to evaluate changes in physical and chemical properties. Results indicated that total nitrogen content in the 0–10 cm layer and bulk density in the 20–40 cm layer increased significantly with stand density, with P5 showing significantly higher values than P1 ($P < 0.05$). Total potassium content in the 0–80 cm layer and pH in the 0–60 cm layer initially increased then decreased with stand density, peaking in P3. Total potassium in the 10–60 cm layer and pH in the 0–40 cm layer were significantly higher in P3 compared to P1 ($P < 0.05$). Total phosphorus content in the 0–10 cm layer decreased with increasing density, with P1 significantly higher than P3–P5 ($P < 0.05$). Available potassium content in the 0–40 cm layer was significantly higher in P4 and P5 compared to P1 and P2 ($P < 0.05$), and also significantly higher than in the 40–100 cm layer of P3 ($P < 0.05$). Porosity in the 40–100 cm layer was lower in P2–P4 than in P1 and P5. Based on these findings, the optimal stand density for mid-aged *P. sylvestris* var. *mongolica* plantations in this region is 1025–1175 plants · hm². Intermediate cutting and other silvicultural measures should be implemented to regulate stand density and maintain favorable soil conditions for sand-fixation forests.

Keywords: *Pinus sylvestris* var. *mongolica*; plantation; stand density; soil property; soil layer; Zhanggutai region

1 Materials and Methods

1.1 Study Area The study was conducted in the Zhanggutai region of Liaoning Province, located in the southeastern part of the Horqin Sandy Land. This

area has a temperate semi-arid continental monsoon climate with an average annual temperature of 4.6–6.3°C, extreme minimum temperature of -33.4°C, and extreme maximum temperature of 43.2°C. Annual precipitation averages approximately 500 mm, concentrated in June–August. The soil is classified as sandy chestnut soil with low fertility. The experimental site consisted of 23–27-year-old *P. sylvestris* var. *mongolica* plantations established on sandy land. The main understory species include *Potentilla chinensis*, *Cleistogenes chinensis*, *Artemisia frigida*, *Lespedeza davurica*, *Ulmus macrocarpa*, *Salix gordejewii*, and *Agriophyllum squarrosum*.

1.2 Experimental Design Five stand density treatments were established: 625 (P1), 775 (P2), 1025 (P3), 1175 (P4), and 1250 (P5) plants · hm². Each treatment had three replicate plots (20 m × 20 m). In August 2016, soil samples were collected from each plot using a soil auger. Samples were taken from six depth intervals: 0–10, 10–20, 20–40, 40–60, 60–80, and 80–100 cm. Three sampling points were randomly selected in each plot and mixed to form a composite sample for each depth layer.

1.3 Soil Analysis Soil bulk density was measured using the core method (100 cm³ stainless steel rings). Soil pH was determined in a 1:2.5 soil-water suspension using a pH meter. Total nitrogen content was measured by the Kjeldahl method, total phosphorus by molybdenum-antimony colorimetry after H₂SO₄-HClO₄ digestion, and total potassium by flame photometry after NaOH fusion. Available potassium was extracted with NH₄OAc and measured by flame photometry. All analyses followed standard procedures.

1.4 Statistical Analysis Data were analyzed using SPSS 20.0 software. One-way ANOVA was performed to examine differences among stand density treatments for each soil layer. When significant differences were detected ($P < 0.05$), least significant difference (LSD) tests were used for multiple comparisons. Significance level was set at $\alpha = 0.05$.

2 Results

2.1 Soil Physical Properties Soil bulk density varied significantly with stand density and soil depth (Fig. 1). In the 0–10 cm layer, bulk density showed no significant differences among density treatments ($P > 0.05$). In the 10–20 cm layer, bulk density in P1 and P2 was significantly lower than in P5 ($P < 0.05$), while other treatments showed no significant differences. In the 20–40 cm layer, bulk density in P5 was significantly higher than in P1 and P0 ($P < 0.05$). In the 40–60 cm layer, bulk density in P2 and P1 was significantly lower than in other treatments ($P < 0.05$). In the 60–80 cm layer, bulk density in P2 and P4 was significantly lower than in P0 ($P < 0.05$), while P4 was significantly higher than P2 ($P < 0.05$). In the 80–100 cm layer, the pattern was similar to the 60–80 cm layer, with P2 significantly lower than P0 and P4 ($P < 0.05$).

Soil porosity in the 40–100 cm layer was significantly lower in P2, P3, and P4 compared to P1 and P5. This suggests that moderate stand densities (P2–P4) may lead to soil compaction in deeper layers.

2.2 Soil Chemical Properties Total nitrogen content in the 0–10 cm layer increased with stand density, with P5 significantly higher than P1 ($P < 0.05$). No significant differences were observed in deeper layers. Total phosphorus content in the 0–10 cm layer decreased with increasing stand density, with P1 significantly higher than P3–P5 ($P < 0.05$). This indicates that higher stand densities may deplete phosphorus in the surface soil.

Total potassium content showed a unimodal response to stand density, peaking in P3. In the 0–80 cm layer, total potassium increased initially then decreased with density, with the highest values in P3. In the 10–60 cm layer, P3 had significantly higher total potassium than P1 ($P < 0.05$). Available potassium content in the 0–40 cm layer was significantly higher in P4 and P5 than in P1 and P2 ($P < 0.05$), and also significantly higher than in the 40–100 cm layer of P3 ($P < 0.05$).

Soil pH showed a similar unimodal pattern, with the highest values in P3. In the 0–60 cm layer, pH increased then decreased with density, peaking in P3. In the 0–40 cm layer, pH in P3 was significantly higher than in other treatments ($P < 0.05$). In the 60–100 cm layer, pH differences among treatments were not significant.

3 Discussion

Stand density significantly influences soil physicochemical properties through litter input, root activity, and microclimate modification. Higher stand densities (P4–P5) increased surface soil nitrogen content, likely due to greater litter accumulation and slower decomposition rates. However, excessive density may reduce understory vegetation diversity, limiting nutrient cycling.

The unimodal response of total potassium and pH to stand density, peaking at P3 (1025 plants · hm²), suggests an optimal density range where nutrient availability is maximized. This may be attributed to balanced litter production and decomposition rates at moderate densities. The decline in total phosphorus with increasing density indicates potential phosphorus limitation in dense stands, possibly due to increased uptake and reduced understory contributions.

Soil bulk density increased with density in deeper layers (20–40 cm), indicating compaction from root growth and organic matter accumulation. Reduced porosity at moderate densities (P2–P4) in deep layers may affect water infiltration and root respiration, highlighting the need for density management.

4 Conclusion

For 23-27-year-old *P. sylvestris* var. *mongolica* plantations in the Zhanggutai region, stand density significantly affects soil physicochemical properties. The optimal density range of 1025-1175 plants · hm² (P3-P4) maintains favorable soil conditions. Management practices such as intermediate cutting should be implemented to regulate stand density, promote understory vegetation development, and sustain soil fertility for long-term sand-fixation forest health.

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