Soil Enzyme Activity and Its Influencing Factors in Pinus sylvestris var. mongolica Plantations on Sandy Land (Postprint)

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Abstract

Path analysis was employed to examine the relationships between multiple soil physicochemical factors and five soil enzyme activities in Mongolian pine (Pinus sylvestris var. mongolica) plantations aged 10–60 years in the Zhanggutai region of Liaoning Province. The results indicated that the five soil enzyme activities were significantly correlated with the majority of soil physicochemical factors, demonstrating that soil enzyme activity can characterize the comprehensive soil fertility status in this region. The primary influencing factors differed among different soil enzyme activities; the comprehensive ranking of main influencing factors for sucrase was: organic matter > clay content > available phosphorus > pH; for protease: alkali-hydrolyzable nitrogen > available potassium > water content; for phosphatase: total phosphorus > available potassium > silt content; for catalase: pH > bulk density > total phosphorus > total potassium; and for urease: pH > clay content > total nitrogen > water content. Compared with simple correlation analysis, path analysis allows for a deeper understanding of the relationships between soil enzyme activities and soil physicochemical factors. It is expected that research on the primary influencing factors of soil enzyme activities will provide a scientific basis for the management and soil improvement of Mongolian pine plantations.

Full Text

1 Materials and Methods

1.1 Study Area

The study was conducted in the Zhanggutai region of Liaoning Province, located at 42°43 -42°51 N, 121°53 -122°22 E. The area has a temperate semi-arid continental monsoon climate with mean annual precipitation of 450–550 mm, mean annual evaporation of 1200-1450 mm, mean annual temperature of 5.7°C, maximum temperature of 35.2°C, and minimum temperature of -29.5°C. The annual average wind speed is 3.2 $\mathrm{m \cdot s^{-1}}$, with 154 frost-free days per year. The soil is classified as cinnamon soil, with main vegetation species including *Potentilla anserina*, *Cleistogenes squarrosa*, *Artemisia frigida*, *Artemisia halodendron*, *Ulmus macrocarpa*, *Salix gordejevii*, and *Agriophyllum squarrosum* [?].

1.2 Experimental Design

Sample plots were established in *Pinus sylvestris* var. *mongolica* plantations of different stand ages (10, 20, 30, 40, 50, and 60 years). Each stand age treatment had three replicate plots of 20 m × 20 m. Within each plot, five sampling points were selected using the diagonal method, and soil samples were collected from six depth layers (0-10 cm, 10-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm). The five soil samples from each layer within a plot were mixed to form one composite sample.

1.3 Soil Sampling and Analysis

Soil enzyme activities were determined using conventional methods: sucrase activity was measured using the 3,5-dinitrosalicylic acid method; protease activity using the ninhydrin colorimetric method; phosphatase activity using the disodium phenyl phosphate method; catalase activity using the potassium permanganate titration method; and urease activity using the indophenol blue colorimetric method [?]. Soil physicochemical properties were analyzed as follows: soil moisture content by the drying method; pH using a pH meter (soil:water ratio of 1:2.5); organic matter content by the dichromate oxidation method; total nitrogen by the Kjeldahl method; total phosphorus by the molybdenum-blue method; total potassium by flame photometry; alkali-hydrolyzed nitrogen by the alkaline hydrolysis diffusion method; available phosphorus by the Olsen method; available potassium by ammonium acetate extraction; and soil particle composition by the pipette method (soil texture fractions: <0.002 mm, 0.002-0.05 mm, and 0.05-2 mm) [?].

2 Results

2.1 Statistical Analysis

Path analysis was used to analyze the relationships between soil physicochemical properties and the five soil enzyme activities. The regression equations obtained were:

$$
\begin{aligned}
Y_1 &= -0.659 + 0.025X_1 + 0.011X_5 + 0.07X_8 + 0.006X_{11} \\
Y_2 &= 0.383 + 0.015X_3 - 0.003X_7 + 0.011X_{10} \\
Y_3 &= 0.305 + 0.133X_4 - 0.002X_7 + 0.055X_{12} \\
Y_4 &= 1.628 - 0.379X_4 + 0.016X_6 - 0.068X_8 - 0.529X_9 \\
Y_5 &= 42.881 + 4.590X_2 - 3.752X_8 + 8.407X_{10} + 19.175X_{11}
\end{aligned}
$$

where Y_1-Y_5 represent sucrase, protease, phosphatase, catalase, and urease activities, respectively; X_1 is soil moisture content; X_2 is clay content; X_3 is organic matter content; X_4 is total nitrogen content; X_5 is total phosphorus content; X_6 is total potassium content; X_7 is alkali-hydrolyzed nitrogen content; X_8 is pH; X_9 is bulk density; X_{10} is available phosphorus content; X_{11} is available potassium content; X_{12} is soil particle composition; X_{13} is soil depth; and X_{14} is stand age.

Table 3 Correlation and path coefficients between soil physicochemical properties and soil enzyme activities

The correlation analysis showed that the five soil enzyme activities were significantly correlated with most soil physicochemical factors ($P < 0.05$), indicating that soil enzyme activities can be used as indicators of comprehensive soil fertility in this region.

For sucrase activity, the main influencing factors were organic matter content, clay content, available phosphorus content, and pH value, with direct path coefficients of 0.597, -0.584, 0.254, and 0.420, respectively. The order of effect magnitude was: organic matter > clay > available phosphorus.

For protease activity, the main influencing factors were alkali-hydrolyzed nitrogen, available potassium, and soil moisture content, with direct path coefficients of 0.433, -0.361, and -0.055, respectively. The order of effect magnitude was: alkali-hydrolyzed nitrogen > available potassium > soil moisture.

For phosphatase activity, the main influencing factors were total nitrogen, available potassium, and soil particle composition, with direct path coefficients of -0.298, 0.233, and -0.542, respectively. The order of effect magnitude was: soil particle composition > total nitrogen > available potassium.

For catalase activity, the main influencing factors were pH, bulk density, total phosphorus, and total potassium, with direct path coefficients of -0.359, 0.491, -0.541, and -0.490, respectively. The order of effect magnitude was: total phosphorus > total potassium > bulk density > pH.

For urease activity, the main influencing factors were pH, clay content, total nitrogen, and soil moisture, with direct path coefficients of 0.464, -0.478, 0.331, and 0.769, respectively. The order of effect magnitude was: soil moisture > pH > clay > total nitrogen.

3 Discussion

The results demonstrate that different soil enzyme activities are affected by different soil physicochemical factors. Compared with simple correlation analysis, path analysis provides a more comprehensive understanding of the relationships between soil enzyme activities and soil properties by separating direct and indirect effects. This approach can better reveal the underlying mechanisms driving soil enzyme activity patterns.

Soil moisture content, pH, and available potassium were the primary factors influencing most enzyme activities. The pH values in the study area ranged from 4.95 to 6.91, which is favorable for microbial activity and enzyme function [**?**]. Soil organic matter and clay content significantly affected sucrase and urease activities, consistent with findings that these enzymes are closely associated with soil organic carbon and nutrient cycling [**?**, **?**].

The stand age of *Pinus sylvestris* var. *mongolica* plantations significantly influenced soil enzyme activities. The 30-year-old plantation showed the highest enzyme activities, suggesting that this age represents an optimal stage for soil biological fertility in this ecosystem. The path analysis revealed that soil moisture and nutrient availability were key drivers of this pattern, with direct effects exceeding those of indirect pathways.

These findings provide a scientific basis for soil improvement and sustainable management of *Pinus sylvestris* var. *mongolica* plantations in sandy areas. By targeting the main factors affecting specific enzyme activities—such as adjusting soil pH, improving moisture retention, and enhancing organic matter content—forest managers can optimize soil fertility and promote healthy plantation development.

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Abstract: Path analysis was used to analyze the soil physicochemical factors and five kinds of soil enzyme activities under *Pinus sylvestris* var. *mongolica* plantations with 10–60 year stand ages in the Zhanggutai area of Liaoning Province. The results showed that the five kinds of soil enzyme activities in the study area were significantly correlated with most soil physicochemical factors, so the soil enzyme activities could be used to characterize the comprehensive soil fertility in this region. The main factors affecting the different soil enzyme activities were different, and the main factors affecting the sucrase enzyme were the contents of organic matter, clay and available phosphorus as well as pH value. The main factors affecting the protease were the contents of alkali-hydrolyzed nitrogen, available potassium and soil moisture. The main factors affecting the phosphatase were the contents of total phosphorus, available potassium and powder. The main factors affecting the catalase were the pH value, bulk density and contents of total phosphorus and total potassium. The main factors affecting the urease were the pH value and the contents of clay, total nitrogen and soil moisture. Compared with the simple correlation analysis, the path analysis could be used to better understand the relationship between soil enzyme activity and soil physicochemical factors. It is expected to provide a basis for soil improvement under *Pinus sylvestris* var. *mongolica* plantation through studying the main factors affecting soil enzyme activity.

Keywords: *Pinus sylvestris* var. *mongolica*; plantation; soil enzyme; enzyme activity; affecting factor; path analysis; Liaoning Province

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