Artificial Afforestation in the Loess Plateau Region: Ecological Benefits of Mixed Forest Patterns postprint

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Abstract

To investigate the amelioration capacity of different plantation types on soil physicochemical properties, this study examined the soil physicochemical properties within the 0-80 cm soil layer across five typical forest stand types (Platycladus orientalis forest, Populus alba var. pyramidalis forest, Robinia pseudoacacia forest, P. orientalis-R. pseudoacacia mixed forest, and P. alba var. pyramidalis-R. pseudoacacia mixed forest) in the north and south mountains of Lanzhou. The results indicated that: (1) Mixed forests exhibited superior soil bulk density, water holding capacity, porosity, soil water content, and infiltration rate compared to pure forests; the soil pH of the two mixed forests and P. orientalis forest was lower than that of R. pseudoacacia forest and P. alba var. pyramidalis forest; soil organic matter, total nitrogen, inorganic nitrogen, and total phosphorus in mixed forests were higher than those in pure forests; total potassium and available potassium showed no significant differences among stand types. (2) Within the 0-80 cm soil layer, soil bulk density gradually increased with soil depth across all stand types; soil water holding capacity and porosity gradually decreased; soil water content and pH showed no significant differences among soil layers; soil organic matter, total nitrogen, inorganic nitrogen, available phosphorus, and available potassium gradually decreased with soil depth, demonstrating a surface accumulation effect; total phosphorus and total potassium showed no significant differences among soil layers. (3) Correlation analysis of soil physicochemical properties revealed that soil organic matter was extremely significantly positively correlated with soil total nitrogen, inorganic nitrogen, total phosphorus, water holding capacity, and porosity, and extremely significantly negatively correlated with soil bulk density; soil bulk density was extremely significantly negatively correlated with soil water holding capacity and porosity. Mixed forests demonstrated superior effectiveness in improving soil physicochemical properties compared to pure forests; it is recommended that mixed forests be prioritized in future afforestation efforts in this region,

and that existing pure forests be considered for conversion to mixed forests during tending and management.

Full Text

Study on the Ecological Benefits of Mixed Plantation Models in the Loess Plateau Region

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Abstract

To investigate the capacity of different plantation types to ameliorate soil physical and chemical properties, this study examined soils in the 0–80 cm layer under five typical plantation types on the north and south mountains of Lanzhou: *Platycladus orientalis* plantation, *Populus alba* var. *pyramidalis* plantation, *Robinia pseudoacacia* plantation, *P. orientalis*–*R. pseudoacacia* mixed plantation, and *P. alba* var. *pyramidalis*–*R. pseudoacacia* mixed plantation. The results demonstrated that (1) mixed plantations exhibited superior soil physical properties compared to pure plantations, including lower bulk density and higher maximum water holding capacity, capillary water holding capacity, field water holding capacity, total porosity, capillary porosity, non-capillary porosity, soil water content, and infiltration rate. The pH values of mixed plantations and the *P. orientalis* plantation were lower than those of *R. pseudoacacia* and *P. alba* var. *pyramidalis* plantations. Mixed plantations also showed greater soil organic matter, total nitrogen, mineral nitrogen, and total phosphorus contents than pure plantations, whereas no significant differences were observed in total potassium and available potassium among plantation types. (2) Within the 0–80 cm soil profile, soil bulk density increased with depth across all plantation types, while water holding capacity and porosity decreased. Soil water content and pH showed no significant variation among soil layers. Soil organic matter, total nitrogen, mineral nitrogen, available phosphorus, and available potassium all decreased with increasing depth, demonstrating surface accumulation effects, whereas total phosphorus and total potassium showed no significant differences among layers. (3) Correlation analysis revealed that soil organic matter was extremely significantly positively correlated with total nitrogen, mineral nitrogen, total phosphorus, water holding capacity, and porosity, but extremely significantly negatively correlated with soil bulk density. Soil bulk density was extremely significantly negatively correlated with water holding capacity and porosity. Mixed plantations proved more effective than pure plantations in improving soil physical and chemical properties. Therefore, we recommend that mixed plantations should be prioritized in future afforestation efforts in this region, and that existing pure plantations be considered for conversion to mixed

configurations.

Keywords: soil physical and chemical properties; pure plantation; mixed plantation; Lanzhou City; Loess Plateau

Introduction

Forest soil constitutes a vital component of forest ecosystems and the fundamental material basis for tree growth. Within ecosystems, trees and soil nutrients are organically linked, mutually influencing one another. Plant communities affect the physical and chemical properties of their growing sites, while soil properties in turn influence numerous ecological processes within communities and directly or indirectly impact tree growth. Soil provides essential nutrients for tree development, and trees return nutrients to the forest floor through litterfall, thereby improving soil structure and influencing soil formation and development. Consequently, evaluating soil physical and chemical properties under different plantation types under identical site conditions helps reveal the relationship between forests and soils.

The north and south mountains of Lanzhou are located in the loess hilly region of the Loess Plateau. Due to the loose loess texture, the area suffers from low erosion resistance, soil collapse, poor permeability, and severe water loss. Since afforestation began in the 1950s, 42,000 hectares of barren hills have been greened, and large-scale plantations have begun to provide ecological benefits. Numerous scholars have conducted extensive research on tree species selection, community structure, and soil nutrients, water, and microorganisms in these plantations. However, during early afforestation stages, emphasis on engineering measures over biological approaches led to excessive site preparation specifications, deep plowing of topsoil, exposure of subsoil, destruction of long-formed soil horizons, reduced hydrological effects, and accelerated water loss. Additionally, failure to fully adhere to the principle of matching tree species to site conditions resulted in poor tree growth and formation of "old-man" trees, limiting plantation ecological benefits. Therefore, studying soil physical and chemical properties of plantations established after large-scale site preparation on Lanzhou' s north and south mountains can elucidate the amelioration capacity of different species compositions and provide references for future species selection.

1 Study Area and Methods

1.1 Study Area Description

The north and south mountains of Lanzhou are located at 35°53 18 -36°33 56 N, 103°21 04 -104°00 38 E, covering approximately 420 km^2. Situated at the westernmost edge of the Loess Plateau, this region belongs to the northern Loess Hills and river valley basin type area of Longzhong in Gansu. The soil is sierozem, with an annual precipitation of 327.7 mm, annual evaporation of 1,468 mm, and mean annual temperature of 9.1 °C. The climate is arid with scarce rainfall, classified as a semi-arid temperate steppe climate. Natural vegetation consists primarily of herbs and a few shrubs, with most vegetation being artificial. Main tree species include *Robinia pseudoacacia*, *Platycladus orientalis*, *Populus alba* var. *pyramidalis*, *Pinus tabulaeformis*, and *Sophora japonica*. This study selected five widely distributed plantation types for soil physical and chemical property analysis. The *P. orientalis* plantation consisted solely of *P. orientalis* trees with no other arboreal or shrub layers. The *R. pseudoacacia* plantation was dominated by *R. pseudoacacia* with minimal *Ulmus pumila* saplings and *Tamarix austrongolica* in the shrub layer. The *P. alba* var. *pyramidalis* plantation contained *P. alba* var. *pyramidalis* with small amounts of *Amorpha fruticosa*, *Tamarix chinensis*, *Caragana korshinskii*, and *Elaeagnus angustifolia* in the shrub layer. The *P. orientalis*-*R. pseudoacacia* mixed plantation had a tree layer composed of both species at a ratio of 5 *P. orientalis* to 5 *R. pseudoacacia* (by quantity), with small amounts of *Caragana korshinskii*, *Tamarix austrongolica*, and *Ulmus pumila* in the shrub layer. The *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation had a tree layer with both species at a ratio of 5 *P. alba* var. *pyramidalis* to 5 *R. pseudoacacia*, with minimal *Tamarix chinensis*, *Ulmus pumila* saplings in the shrub layer. Additional stand details are provided in .

1.2 Methods

1.2.1 Soil Sample Collection Based on preliminary surveys, five representative plantation types with similar establishment times were selected on Lanzhou's north and south mountains in October 2018. For each plantation type, three 10 m × 10 m representative plots were established. Within each plot, three sampling points were randomly selected along the diagonal, positioned at the intersection of diagonals between four trees to avoid proximity to dense root zones near tree bases that could affect data accuracy. At each sampling point, a soil profile was excavated, and samples were collected from 0–20 cm, 20–40 cm, 40–60 cm, and 60–80 cm layers. Samples from the same layer within a plot were mixed to obtain a 0.5 kg composite sample, which was air-dried in the laboratory, impurities were removed, and the sample was sieved through 0.149 mm mesh for chemical property analysis. Undisturbed soil cores were collected from 0–20 cm, 20–40 cm, 40–60 cm, and 60–80 cm layers using a cutting ring (50 mm diameter × 50 mm height) for physical property analysis, with three replicates per layer.

1.2.2 Measurement Indicators and Methods Physical properties: Soil bulk density, total porosity, and capillary porosity were measured using the cutting ring method; soil natural water content was determined by the oven-drying method; and soil permeability was measured using the double-ring infiltrometer method. Chemical properties: Soil organic matter was determined by the potassium dichromate volumetric method; total nitrogen by the semi-micro Kjeldahl method; pH by the potentiometric method; mineral nitrogen by NaCl extraction followed by continuous flow analyzer measurement; total phosphorus by the molybdenum-antimony anti-colorimetric method; available phosphorus by $NaHCO_3$ extraction colorimetry; total potassium by flame photometry; and available potassium by ammonium acetate extraction flame photometry. All methods followed standard soil agrochemical analysis procedures.

1.3 Data Analysis

SPSS 19.0 software was used for variance analysis, multiple comparisons, and correlation analysis.

2 Results

2.1 Soil Physical Properties

2.1.1 Soil Bulk Density Significant differences in soil bulk density were observed among plantation types ($P < 0.05$), ranging from 1.22 to 1.36 $g \cdot cm^{-3}$. The ranking was *P. orientalis* plantation > *R. pseudoacacia* plantation > *P. alba* var. *pyramidalis* plantation > *P. orientalis*-*R. pseudoacacia* mixed plantation > *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation. Bulk density in the *P. orientalis* plantation was 1.11 times that of the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation, with mixed plantations showing lower bulk density than pure plantations. Soil bulk density varied significantly across the 0-80 cm profile ($P < 0.05$), increasing with depth from 1.17-1.40 $g \cdot cm^{-3}$. Specifically, bulk density in the 40-60 cm and 60-80 cm layers was 1.06 and 1.09 times that of the 0-20 cm layer, respectively.

2.1.2 Soil Porosity Significant differences in total porosity were found among plantation types ($P < 0.05$), ranging from 49.14% to 53.84%. The ranking was *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation > *P. orientalis*-*R. pseudoacacia* mixed plantation > *P. alba* var. *pyramidalis* plantation > *R. pseudoacacia* plantation > *P. orientalis* plantation. Total porosity in the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation was 1.10 times that of the *P. orientalis* plantation, with mixed plantations exhibiting higher total porosity than pure plantations. Total porosity varied significantly across the soil profile ($P < 0.05$), decreasing with depth from 47.82%-55.31%. The 0-20 cm layer showed 1.07, 1.09, and 1.16 times the total porosity of the 20-40 cm, 40-60 cm, and 60-80 cm layers, respectively.

Significant differences in capillary porosity were observed among plantation types ($P < 0.05$), ranging from 43.68% to 46.37%. The ranking was *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation > *P. orientalis*-*R. pseudoacacia* mixed plantation > *P. alba* var. *pyramidalis* plantation > *R. pseudoacacia* plantation > *P. orientalis* plantation. Capillary porosity in the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation was 1.06 times that of the *P. orientalis* plantation, with mixed plantations showing higher capillary porosity than pure plantations. Capillary porosity varied significantly across the soil profile ($P < 0.05$), decreasing with depth from 42.19%-47.67%. The 0-20 cm layer exhibited 1.05, 1.08, and 1.13 times the capillary porosity of the 20-40 cm, 40-60 cm, and 60-80 cm layers, respectively.

No significant differences in non-capillary porosity were detected among plantation types ($P > 0.05$), with values ranging from 5.33% to 7.48%. However, significant differences were found across soil layers ($P < 0.05$), with non-capillary porosity decreasing with depth from 5.63%-7.64%. The 0-20 cm layer showed 1.13, 1.19, and 1.21 times the non-capillary porosity of the 20-40 cm, 40-60 cm, and 60-80 cm layers, respectively.

2.1.3 Soil Water Holding Capacity Significant differences in maximum water holding capacity were observed among plantation types ($P < 0.05$), ranging from 41.09% to 52.75%. The *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation showed the highest value, while the *P. orientalis* plantation showed the lowest, with mixed plantations outperforming pure plantations. Maximum water holding capacity varied significantly across the soil profile ($P < 0.05$), decreasing with depth. The 0-20 cm layer exhibited 1.12, 1.22, and 1.34 times the maximum water holding capacity of the 20-40 cm, 40-60 cm, and 60-80 cm layers, respectively.

Significant differences in both capillary water holding capacity and field water holding capacity were found among plantation types ($P < 0.05$), with the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation showing the highest values and the *P. orientalis* plantation the lowest. Both parameters were higher in mixed than in pure plantations and decreased significantly with soil depth ($P < 0.05$).

2.1.4 Soil Water Content Significant differences in soil water content were observed among plantation types ($P < 0.05$), ranging from 4.36% to 13.82%. Mixed plantations showed higher soil water content than pure plantations. However, no significant differences were found across soil layers ($P > 0.05$), with values ranging from 6.78% to 11.35%.

Soil infiltration rates for all plantation types decreased with depth, as shown in [Figure 1: see original paper]. Significant variation in infiltration rates occurred among plantation types, with differences diminishing at greater depths. In the 0-20 cm layer, the ranking was *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation > *P. orientalis*-*R. pseudoacacia* mixed plantation > *R. pseudoacacia* plantation > *P. orientalis* plantation > *P. alba* var. *pyramidalis* plantation. In the 20-40 cm layer, the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation showed higher infiltration rates than other types, though differences were not significant. In the 40-60 cm and 60-80 cm layers, no significant differences were observed among plantation types.

2.2 Soil Chemical Properties

2.2.1 Soil pH Significant differences in soil pH were detected among plantation types ($P < 0.05$), ranging from 8.02 to 8.36. According to China' s soil pH classification, the study area has alkaline soils. No significant differences in pH were observed across soil layers, with values ranging from 8.10 to 8.23. Soil pH showed no clear trend with increasing depth.

2.2.2 Soil Organic Matter Significant differences in soil organic matter content were found among plantation types ($P < 0.05$), ranging from 6.11 to 11.67 $g \cdot kg^{-1}$. Mixed plantations showed higher organic matter than pure plantations, with the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation exhibiting 1.91 times the organic matter of the *P. alba* var. *pyramidalis* plantation. Soil organic matter varied significantly across the soil profile ($P < 0.05$), decreasing with depth from 3.87–15.99 $g \cdot kg^{-1}$. The surface layer (0–20 cm) showed significantly higher organic matter than deeper layers.

2.2.3 Soil Nitrogen Significant differences in both total nitrogen and mineral nitrogen were observed among plantation types ($P < 0.05$), ranging from 0.40–0.68 $g \cdot kg^{-1}$ and 12.66–33.22 $mg \cdot kg^{-1}$, respectively. Both parameters were higher in mixed than in pure plantations, with the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation showing 1.70 and 2.63 times the total nitrogen and mineral nitrogen, respectively, of the *P. alba* var. *pyramidalis* plantation. Both total nitrogen and mineral nitrogen varied significantly across the soil profile ($P < 0.05$), decreasing with depth from 0.31-0.76 $g \cdot kg^{-1}$ and 12.54–30.95 $mg \cdot kg^{-1}$, respectively.

2.2.4 Soil Phosphorus Significant differences in total phosphorus were found among plantation types ($P < 0.05$), ranging from 0.63 to 0.75 $g \cdot kg^{-1}$, with mixed plantations showing higher values than pure plantations. The *P. orientalis*-*R. pseudoacacia* mixed plantation exhibited 1.19 times the total phosphorus of the *P. orientalis* plantation. No significant differences in total phosphorus were observed across soil layers ($P > 0.05$), with values ranging from 0.66 to 0.73 $g \cdot kg^{-1}$, and no clear trend with depth.

Significant differences in available phosphorus were detected among plantation types ($P < 0.05$), ranging from 3.44 to 5.66 $mg \cdot kg^{-1}$. The ranking was *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation > *P. alba* var. *pyramidalis* plantation > *R. pseudoacacia* plantation > *P. orientalis* plantation > *P. orientalis*-*R. pseudoacacia* mixed plantation, with the *P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation showing 1.64 times the available phosphorus of the *P. orientalis*-*R. pseudoacacia* mixed plantation. Available phosphorus varied significantly across soil layers ($P < 0.05$), decreasing with depth.

2.2.5 Soil Potassium No significant differences in total potassium were observed among plantation types ($P > 0.05$) or across soil layers ($P > 0.05$), with values ranging from 17.25 to 18.77 $g \cdot kg^{-1}$. No clear trend with depth was evident.

No significant differences in available potassium were found among plantation types ($P > 0.05$), but significant differences were detected across soil layers ($P < 0.05$), with values ranging from 57.04 to 85.50 $mg \cdot kg^{-1}$ and decreasing with depth.

2.3 Correlation Analysis of Soil Physical and Chemical Properties

Correlation analysis among physical and chemical properties across all plantation types revealed that soil organic matter was extremely significantly positively correlated with total nitrogen, mineral nitrogen, total phosphorus, maximum water holding capacity, capillary water holding capacity, field water holding capacity, capillary porosity, and total porosity, significantly positively correlated with non-capillary porosity, and extremely significantly negatively correlated with bulk density. Total nitrogen was extremely significantly positively correlated with mineral nitrogen, maximum water holding capacity, capillary water holding capacity, field water holding capacity, capillary porosity, non-capillary porosity, and total porosity, and extremely significantly negatively correlated with bulk density. Mineral nitrogen was extremely significantly positively correlated with maximum water holding capacity, capillary water holding capacity, field water holding capacity, capillary porosity, and total porosity, significantly positively correlated with total phosphorus and non-capillary porosity, and extremely significantly negatively correlated with bulk density. Total phosphorus was extremely significantly negatively correlated with total potassium. Bulk density was extremely significantly negatively correlated with maximum water holding capacity, capillary water holding capacity, field water holding capacity, capillary porosity, non-capillary porosity, and total porosity. These results indicate that soil physical and chemical properties are interrelated, with changes in soil organic matter playing a key role in altering other properties.

3 Discussion

3.1 Soil Physical Properties of Different Plantation Types

Different plantation types exhibit varying soil physical properties due to differences in root development and annual litter accumulation and decomposition. This study found that mixed plantations had better soil bulk density and porosity than pure plantations, likely related to both root distribution patterns and litter input quantity and decomposition rates. Research indicates that *R. pseudoacacia* roots are concentrated primarily in the 0–40 cm layer, with 90% distributed within 0-120 cm, while *P. orientalis* roots are mainly distributed in the 0–50 cm layer. Thus, mixed plantations with deep- and shallow-rooted species complementary distributions expand nutrient absorption space. Greater root extension increases soil porosity and reduces bulk density. Additionally, as a nitrogen-fixing species, *R. pseudoacacia* enhances soil mineral nitrogen through nitrogen fixation, promoting growth of associated *P. alba* var. *pyramidalis* and *P. orientalis* trees. Mixed plantations therefore accumulate larger quantities of litter (47.01 $t \cdot hm^{-2}$ for *P. alba* var. *pyramidalis*–*R. pseudoacacia* mixed plantation; 42.93 $t \cdot hm^{-2}$ for *P. orientalis*–*R. pseudoacacia* mixed plantation), inputting more organic matter that increases soil permeability, reduces bulk density, and increases porosity. The *P. orientalis* plantation showed the highest bulk density and lowest porosity, likely because coniferous litter decomposes relatively slowly, resulting in less organic matter return.

Soil water is a crucial component of forest ecosystems and an important link in the water cycle, significantly affecting nutrient transport and plant growth. This study found that mixed plantations had higher soil water content than pure plantations due to greater litter accumulation that enhances rainfall interception and reduces soil water evaporation. All plantation types showed decreasing soil water content with depth, as precipitation is the primary water source in this semi-arid region, and water supply decreases with soil depth, consistent with findings from Xinglong Mountain. Differences in water holding capacity among plantation types were also observed, with mixed plantations outperforming pure plantations due to higher porosity that facilitates greater water retention.

Soil permeability is a key indicator for evaluating soil hydrological effects and reflects water conservation and soil erosion control capacity. Permeability is influenced by rainfall characteristics, plantation type, stand structure, density, root distribution, and litter accumulation. This study found that mixed plantations had better permeability than pure plantations, effectively reducing surface runoff and soil erosion while promoting infiltration and increasing soil water content. This result stems from higher non-capillary porosity in mixed plantations. Research by Zhao Yangyi et al. demonstrated that soil permeability indicators are extremely significantly positively correlated with non-capillary porosity but not significantly correlated with capillary porosity, indicating that non-capillary porosity plays a more important role in permeability. This study similarly found correlation coefficients between soil permeability characteristics (initial infiltration rate, stable infiltration rate, average infiltration rate, and total infiltration) and non-capillary porosity of 0.87*, 0.89**, 0.86*, and 0.91**, respectively, showing significant or extremely significant positive correlations.

3.2 Soil Chemical Properties of Different Plantation Types

Soil pH, an indicator of soil acidity or alkalinity, varies among plantation types due to differences in litter composition. This study found that soils in the research area were alkaline, with pH values ranging from 8.02 to 8.34 and showing significant differences among plantation types. Mixed plantations and the *P. orientalis* plantation had lower pH values than *R. pseudoacacia* and *P. alba* var. *pyramidalis* plantations. The lower pH in mixed plantations is attributed to moister soil conditions that enhance microbial activity, accelerating organic matter decomposition and producing more CO_2 and organic acids. Studies have shown that coniferous forests produce more organic acids and fewer bases during long-term development, leading to soil acidification.

Soil organic matter is a crucial indicator of soil fertility, providing essential nutrients for plant growth and energy for soil microorganisms, while significantly affecting physical, chemical, and biological properties. This study found that soil organic matter decreased with depth, with mixed plantations showing significantly higher organic matter than pure plantations ($P < 0.05$), similar to findings by Chen Ruimei et al. Litter is the primary source of forest soil organic matter, creating surface accumulation effects. Lu Xiang et al. demonstrated that mixed plantations with thicker canopies and larger leaf area indices accumulate more litter with complex composition, improving soil fertility more effectively than pure plantations. Mixed plantations also reduce soil water evaporation, increase air humidity, and accelerate litter decomposition, thereby enhancing organic matter content.

Total nitrogen, total phosphorus, and total potassium represent soil nutrient reserves, while mineral nitrogen, available phosphorus, and available potassium reflect real-time nutrient supply capacity. This study found that mixed plantations had higher total nitrogen and mineral nitrogen than pure plantations, with both parameters decreasing with depth. This pattern occurs because forest soil nitrogen primarily originates from litter, and mixed plantations accumulate more litter than pure plantations, consistent with Lu Xiang et al.' s findings. No significant differences in total phosphorus were observed across soil layers, and no significant differences in total potassium and available potassium were detected among plantation types, because soil phosphorus and potassium primarily originate from rock weathering and mineral formation. Since soil parent material is essentially the same within the region, differences in phosphorus and potassium among soil depths and plantation types are minimal, consistent with Wei Qiang et al.' s research on soil properties under different forest types.

3.3 Relationships Between Soil Physical and Chemical Properties

This study revealed correlations between soil physical and chemical properties across all plantation types. Organic matter was significantly positively correlated with total nitrogen, mineral nitrogen, total phosphorus, water holding capacity, and porosity, and significantly negatively correlated with bulk density, consistent with findings by Chang Chao et al. in the Three Gorges Reservoir area and Wei Qiang et al. in Xinglong Mountain. Differences in soil properties among plantation types result from varying litter input and decomposition rates. Mixed plantations, particularly the *P. alba* var. *pyramidalis*–*R. pseudoacacia* mixed plantation, accumulated the largest litter quantity ($47.01\ t \cdot hm^{-2}$) with the highest decomposition rate (66.49%), increasing soil nutrient accumulation. Enhanced soil organic matter improved porosity and water holding capacity while reducing bulk density, creating better growing conditions for trees.

4 Conclusions

1) Mixed plantations exhibited superior soil physical properties compared to pure plantations, including bulk density, water holding capacity, porosity, water content, and infiltration rate. The optimal plantation type (*P. alba* var. *pyramidalis*-*R. pseudoacacia* mixed plantation) showed bulk density of 1.22 $g \cdot cm^{-3}$, maximum water holding capacity of 52.75%, field water holding capacity of 33.56%, and total porosity of 53.84%. Mixed plantations also had higher soil organic matter, total nitrogen, mineral nitrogen, and total phosphorus than pure plantations, with the optimal plantation type showing organic matter of 11.67 $g \cdot kg^{-1}$ and total nitrogen of 0.68 $g \cdot kg^{-1}$. No significant differences were observed in total potassium and available potassium among plantation types.

2) Within the 0–80 cm soil profile, bulk density increased with depth, while water holding capacity and porosity decreased. Soil water content and pH showed no significant differences among layers. Soil organic matter, total nitrogen, mineral nitrogen, available phosphorus, and available potassium decreased with depth, demonstrating surface accumulation, whereas total phosphorus and total potassium showed no significant differences among layers.

3) Correlation analysis revealed that soil organic matter was extremely significantly positively correlated with total nitrogen, mineral nitrogen, total phosphorus, water holding capacity, and porosity, and extremely significantly negatively correlated with bulk density. Changes in soil organic matter play a key role in altering other soil properties. Mixed plantations demonstrated superior performance in improving soil physical and chemical properties compared to pure plantations. Therefore, we recommend that mixed plantations should be the primary approach for future afforestation in this region, and that existing pure plantations should be considered for transformation into mixed configurations.

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