

MEDIUM AND LONG-TERM INFLUENCES OF TYPICAL PLANTATIONS ON SURFACE SOIL NUTRIENTS IN THE TEMPERATE ZONE OF MOUNT MENG, CHINA

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Abstract. Very few studies are concerned with the medium and long-term soil nutrients of plantations, which often have inconsistent research results. This paper studied the characteristics of the surface soil nutrient changes in two types of plantations with different stand age: 30 years and 60 years. They are needle-leaved plantations (*Pinus thunbergii* plantation and *Pinus densiflora* plantation) and broad-leaved plantations (*Quercus variabilis* plantation). Research results showed: 1) When the stand age is 30 years, the content of organic matters and the nitrogen of the surface soil was presented as follows: *Pinus thunbergii* plantation > *Quercus variabilis* plantation > *Pinus densiflora* plantation, and the content of organic carbon, available phosphate and rapidly available potassium of the surface soil was presented as follows: *Quercus variabilis* plantation > *Pinus thunbergii* plantation > *Pinus densiflora* plantation. Significant differences were found in the content of active organic carbon in the surface soil. 2) When the stand age is 60 years, the content of organic matters, the total nitrogen and rapidly available potassium in the surface soil was presented as follows: *Pinus densiflora* plantation > *Quercus variabilis* plantation > *Pinus thunbergii* plantation and significant differences were found in the content of organic matters and total nitrogen of the surface soil. The content of active organic carbon in the surface soil was ranked as follows: *Pinus thunbergii* plantation > *Pinus densiflora* plantation > *Quercus variabilis* plantation. 3) Among the plantations with 60-year stand age, the content of five nutrients all increased in the surface soil of the *Pinus densiflora* plantation, namely, organic matters, active organic carbon, total nitrogen, available phosphorus and rapidly available potassium. The content of organic matters, total nitrogen and available phosphorus significantly increased in the surface soil, but no significant differences were found in the surface soil nutrient content of *Quercus variabilis* plantation and *Pinus thunbergii* plantation.

Keywords: plantation, soil nutrient, organic matter, active organic carbon, total nitrogen, available phosphorus, available potassium

Introduction

At the Asia-Pacific Regional Conference on Forest Restoration on March 26, 2018, Peng Y. D., deputy director of the State Forestry Administration, pointed out that as of 2017, China's plantation forest area was 693,300 km², ranking first in the world. Forest plantation is a major measure to recover the degraded ecosystem and conserve the ecosystem service functions (Togonidze and Akhalkatsi, 2015; Wei et al., 2017; Yin et al., 2018). In the forest ecosystem, the vegetation of plantations influences a lot of ecological processes above and below the ground, and plays a crucial role in maintaining the stability and diversification of the forest ecological system (Nilsson and Wardle, 2005). In the ecological restoration of the forest, the changes of soil nutrients have been a focus of the modern ecological research. Soil, an important component of

the forest ecosystem, provides necessary nutrients for the growth and propagation of plants as well as serves as carriers to the multiple ecological processes in the ecosystem (Trumbore and Czimczik, 2008). The status of forest soil nutrients is influenced by factors like climate, soil types and vegetation types together (Roy et al., 2010; Schmidt et al., 2015; Hedwall et al., 2015). Soil nutrients are important quantitative indexes of soil fertility, and they are crucial to the species composition and structural changes of vegetation. Moreover, they directly influence the productivity level of the ecosystem (Xu et al., 2008; Schmidt et al., 2015). The forest succession and the compound afforestation pattern obviously influence the soil fertility (Rutigliano et al., 2004; Hedwall et al., 2015). Vegetation influences the characteristics and development of the soil because the changes accompanying the vegetation succession, plant litters and root exudates directly influence the quantity of the input soil nutrients (Jia et al., 2005). Different development stages of plantations are throughout the whole life cycle of the forest growth. Therefore, it is of great ecological significance to understand the soil fertility of different development stages and the fertilizer requirement characteristics of forests in the plantation management. It could provide the scientific basis for the operation and management of the local plantations and evaluate the ecological consequences of the introduced exotic tree species.

The existing experimental research shows that broad-leaved species could immobilize more nutrients than coniferous species in the restoration of the forest the stand age of which is less than 30 years (Laganière et al., 2010; Li et al., 2012; Nave et al., 2013). However, the research ignores the changes of the soil nutrient storage in the restoration of the forest the stand age of which is over 30 years (Wang et al., 2016). Coniferous species are more difficult to resolve than broad-leaved species. Theoretically, the former is higher than the latter in the quantity of the immobilized soil nutrients (Vesterdal et al., 2008; Wang et al., 2016). These research inconsistencies reflect that: the soil nutrient data of the medium and long term plantations (trees whose stand age is over 30 years) are required for the research, especially those plantations with over 50 years of stand age because of their scarcity and preciousness (Bai et al., 2008; Gao et al., 2013).

Mount Meng is located in the low hilly areas of the central-south Shandong Province of China, and it is one of the two major ecological reserves in Shandong. Meanwhile, it is also a typical representative of the rocky mountain areas in northern China as well as one of the earliest areas to develop plantations in China. Typical plantations are *Pinus thunbergii* (black pine) plantation, *Pinus densiflora* (red pine) plantation and *Quercus variabilis* (cork oak) plantation (Gao et al., 2009, 2011, 2013). According to different forest types, studies relevant to surface soil nutrients and their dynamics are conducted, which helps to understand the surface soil nutrient supply of the forest ecosystem. This study will explore the soil surface nutrient changes of needle plantations (*Pinus thunbergii* plantation and *Pinus densiflora* plantation) and broad-leaf plantations (*Quercus variabilis* plantation) in terms of the stand age: 30 years and 60 years. The presupposed scientific hypotheses of the study are as follows: 1) Litters of coniferous species are more difficult to resolve than those of broad-leaf species. If the stand age of plantations are the same, more surface soil nutrients should be accumulated, namely, needle plantations are higher than broad-leaf plantations in the content of soil surface nutrients when their stand age are both 60 years. 2) The content of soil surface nutrients of plantations increases progressively along with the time, namely, the 60-year plantations have more soil surface nutrients than the 30-year plantations.

Materials and methods

Research sample plot

The research was conducted in typical areas of Mount Meng. Located in the warm temperate zone of the southeastern hilly areas in Shandong Province, Mount Meng covers an area of 1,125 square kilometers, and its soil is the brown forest soil. The research selected *Pinus thunbergii* plantation, *Pinus densiflora* plantation and *Quercus variabilis* plantation with two types of stand age—30a and 60a as research plots by investigating the community structure of wild plants and interviewing the technicians of the forest station in order to carry out the soil sampling. Forest in this area has been damaged by man-made for a long time. In 1949, only about 25 km² of forest was left, the forest coverage rate was less than 2%, and there were less than 300 plant species. The government has successively established 7 forest farms in Tashan, Wanshou Palace, Tianma, Mingguang Temple, Datun, Hailuo Temple and Tianbao Mountain to restore and reconstruct Mengshan vegetation from the 1950s to the 1980s.

Research methods

The sample plots were selected as follows: 12 sample plots of *Pinus thunbergii* plantation (6 sample plots with 30 years of stand age and 6 sample plots with 60 years of stand age), 12 sample plots of *Pinus densiflora* plantation (6 sample plots with 30 years of stand age and 6 sample plots with 60 years of stand age), and 16 sample plots of *Quercus variabilis* plantation (8 sample plots with 30 years of stand age and 8 sample plots with 60 years of stand age). The sampling area coordinates were 35°10'~36°00'N, 117°35'~118°20' E. The plot spacing is more than 1 km. There was no garbage in the plot, and the roots of the plant were dried when the soil sample was treated.

1 quadrat of 20 m × 30 m was selected in each sample plot, and the five-point sampling method was used to drill 5 repeated soil samples. The diameter of the earth boring auger was 3.5 cm and the sampling depth was 10 cm (Wang et al., 2017). Then, the repeated soil samples were mixed into one soil sample and taken to the lab. Sampling was conducted in August, 2016, and the lab was responsible for the assay determination of organic matters, active organic carbon, total nitrogen, available phosphorus and rapidly available potassium of the soil samples. According to the LY/T1237-1999 standard for the organic matters of forest soil, the external heating method of potassium dichromate was used for measuring the organic matters of soil, and the potassium permanganate oxidation method was adopted for measuring the content of active organic matters. According to the LY/T 1228-2015 standard of nitrogen measurement for the forest soil, the Kjeldahl nitrogen method was used to measure the content of total nitrogen. According to the LY/T 1232-2015 standard of phosphorous measurement for the forest soil, the colorimetric method was used for measuring the phosphorous content. According to the LY/T 1234-2015 standard of potassium measurement for the forest soil, the atomic absorption spectrophotometer was used for the rapidly available potassium measurement.

Statistical analysis

The single factor statistical method was used to analyze the soil nutrient differences of the forest type, and T test was applied to measure the soil nutrient differences of the

plantations with different stand age. SPSS 17.0 and Excel 2003 were used for the data analysis and table introduction.

Results and analysis

Organic matters of surface soil

In plantations with the same stand age but different forest types, the organic matter content was as follows: 1) when the stand age of plantations is 30 years, *Pinus thunbergii* plantations ($33.03 \pm 8.86 \text{ g}\cdot\text{kg}^{-1}$) > *Quercus variabilis* plantation ($28.78 \pm 5.33 \text{ g}\cdot\text{kg}^{-1}$) > *Pinus densiflora* plantation ($24.40 \pm 11.26 \text{ g}\cdot\text{kg}^{-1}$). 2) when the stand age of plantations is 60 years, *Pinus densiflora* plantation ($64.02 \pm 11.06 \text{ g}\cdot\text{kg}^{-1}$) > *Quercus variabilis* plantation ($46.6 \pm 11.48 \text{ g}\cdot\text{kg}^{-1}$) > *Pinus thunbergii* plantations ($29.20 \pm 4.95 \text{ g}\cdot\text{kg}^{-1}$). And *Pinus densiflora* plantation was significantly higher than the other two types of plantations in terms of the organic matter content (Fig. 1A).

In plantations with the same forest type but different stand age, the organic matter content of the surface soil was as follows: three plantations with 60 years of stand age had more organic matters than those with 30 years of stand age, where the *Pinus densiflora* plantation with 60 years of stand age is significantly higher than that with 30 years of stand age in terms of the organic matter content (Fig. 1A).

Active organic carbon of surface soil

In plantations with the same stand age but different forest types, the content of active organic carbon of surface soil was as follows: 1) when the stand age of plantations is 30 years, *Quercus variabilis* plantation ($22.80 \pm 1.87 \text{ g}\cdot\text{kg}^{-1}$) > *Pinus thunbergii* plantation ($14.21 \pm 2.22 \text{ g}\cdot\text{kg}^{-1}$) > *Pinus densiflora* plantation ($12.06 \pm 3.66 \text{ g}\cdot\text{kg}^{-1}$), where *Quercus variabilis* plantation was significantly higher than the other two types of plantations in terms of the content of active organic carbon. 2) When the stand age of plantations is 60 years, *Pinus thunbergii* plantation ($20.39 \pm 0.34 \text{ g}\cdot\text{kg}^{-1}$) > *Quercus variabilis* plantation ($20.30 \pm 0.41 \text{ g}\cdot\text{kg}^{-1}$) > *Pinus densiflora* plantation ($19.87 \pm 0.34 \text{ g}\cdot\text{kg}^{-1}$) (Fig. 1B).

In plantations with the same forest type but different stand age, the content of active organic carbon of surface soil was as follows: 1) the group of *Pinus thunbergii* plantation and *Pinus densiflora* plantation with 60 years of stand age were higher than the group with 30 years of stand age, while the *Quercus variabilis* plantation group with 60 years of stand age was lower than the group with 30 years of stand age in terms of the active organic carbon content (Fig. 1B).

Total nitrogen of surface soil

In plantations with the same stand age but different forest types, the content of total nitrogen of surface soil was as follows: 1) When the stand age of plantations is 30 years, *Pinus thunbergii* plantation ($1.54 \pm 0.44 \text{ g}\cdot\text{kg}^{-1}$) > *Quercus variabilis* plantation ($1.43 \pm 0.37 \text{ g}\cdot\text{kg}^{-1}$) > *Pinus densiflora* plantation ($1.14 \pm 0.32 \text{ g}\cdot\text{kg}^{-1}$). 2) When the stand age of plantations is 60 years, *Pinus densiflora* plantation ($2.56 \pm 0.50 \text{ g}\cdot\text{kg}^{-1}$) > *Quercus variabilis* plantation ($1.65 \pm 0.34 \text{ g}\cdot\text{kg}^{-1}$) > *Pinus thunbergii* plantation ($1.22 \pm 0.23 \text{ g}\cdot\text{kg}^{-1}$), where *Pinus densiflora* plantation was significantly higher than the other two types of plantations in terms of the total nitrogen content of surface soil (Fig. 1C).

In plantations with the same forest type but different stand age, the total nitrogen content of surface soil was as follows: the *Pinus densiflora* plantation group with 60 years of stand age was significantly higher than the group with 30 years of stand age in terms of the total nitrogen content, but the *Pinus thunbergii* plantation group with 60 years of stand age was lower than the group with 30 years of stand age. Contrarily, the *Quercus variabilis* plantation group with 60 years of stand age was higher than the group with 30 years of stand age in terms of the total nitrogen content of surface soil.

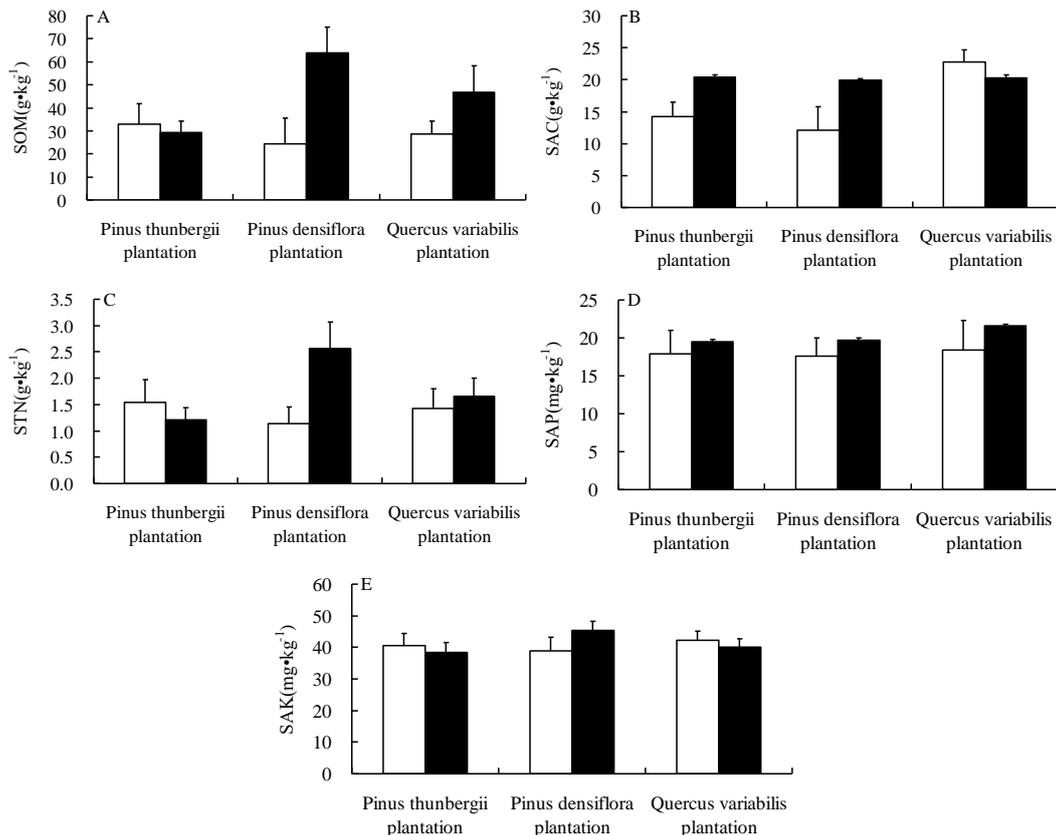


Figure 1. Content difference of soil organic matter (SAM, A), soil active organic carbon (SAC, B), soil total nitrogen (STN, C), soil available phosphorus (SAP, D) and soil available potassium (SAK, E) of *Pinus thunbergii* plantation, *Pinus densiflora* plantation and *Quercus variabilis* plantation in 30 years of age and 60 years of age in Mount Meng (average + standard error). □ 30 years of age; ■ 60 years of age

Available phosphorus of surface soil

In plantations with the same stand age but different forest types, the available phosphorus content of surface soil was as follows: 1) When the stand age of plantation is 30 years, *Quercus variabilis* plantation ($18.43 \pm 3.85 \text{ mg}\cdot\text{kg}^{-1}$) > *Pinus thunbergii* plantation ($17.85 \pm 3.15 \text{ mg}\cdot\text{kg}^{-1}$) > *Pinus densiflora* plantation ($17.64 \pm 2.38 \text{ mg}\cdot\text{kg}^{-1}$). 2) When the stand age of plantation is 60 years, *Quercus variabilis* plantation ($21.65 \pm 0.18 \text{ mg}\cdot\text{kg}^{-1}$) > *Pinus densiflora* plantation ($19.74 \pm 0.21 \text{ mg}\cdot\text{kg}^{-1}$) > *Pinus thunbergii* plantation ($19.55 \pm 0.26 \text{ mg}\cdot\text{kg}^{-1}$) (Fig. 1D).

In plantations with the same forest type but different stand age, the available phosphorus content of surface soil was as follows: 1) The three types of plantations with 60 years of stand age were higher than those with 30 years of stand age in terms of the available phosphorus content of surface soil, where the *Pinus densiflora* plantation group with 60 years of stand age had significantly more available phosphorus than the group with 30 years of stand age (Fig. 1D).

Rapidly available potassium of surface soil

In plantations with the same stand age but different forest types, the rapidly available potassium content of surface soil was as follows: 1) When the stand age of plantation is 30 years, *Quercus variabilis* plantation ($42.20 \pm 2.86 \text{ mg}\cdot\text{kg}^{-1}$) > *Pinus thunbergii* plantation ($40.53 \pm 3.93 \text{ mg}\cdot\text{kg}^{-1}$) > *Pinus densiflora* plantation ($45.37 \pm 2.77 \text{ mg}\cdot\text{kg}^{-1}$). 2) When the stand age of plantation is 60 years, *Pinus densiflora* plantation ($45.37 \pm 2.77 \text{ mg}\cdot\text{kg}^{-1}$) > *Quercus variabilis* plantation ($40.09 \pm 2.64 \text{ mg}\cdot\text{kg}^{-1}$) > *Pinus thunbergii* plantation ($38.43 \pm 3.15 \text{ mg}\cdot\text{kg}^{-1}$) (Fig. 1E).

In plantations with the same forest type but different stand age, the rapidly available potassium content of surface soil was as follows: 1) in terms of the rapidly available potassium content, the *Pinus densiflora* plantation group with 60 years of stand age was higher than the group with 30 years of stand age, while the other two types of plantations with 60 years of stand age were lower than those with 30 years of stand age (Fig. 1E).

Principal component analysis of soil nutrients

The accumulative variance contribution rates of the first and second principal components respectively reached 81.05% and 80.81% in Mount Meng's plantations with 30 years and 60 years of stand age as shown in Tables 1 and 2, which revealed the majority of information. In Mount Meng's plantations with 30 years and 60 years of stand age, the first principal component was closely relevant to organic matters, total nitrogen, available phosphorus and rapidly available potassium, with the accumulative variance contribution rates being 59.85% and 59.05% as shown in Table 1 and Figure 2A. In Mount Meng's plantations with 30 years and 60 years of stand age, the second principal component was closely relevant to the active organic carbon of the soil with the accumulative variance contribution rates being 21.20% and 21.76% as shown in Table 2 and Figure 2B.

Table 1. Soil nutrients of 30a plantation in principal component analysis in Mount Meng, China

	SAM	SAC	STN	SAP	SAK
Main component 1	0.95	-0.11	0.91	0.88	0.70
Main component 2	0.05	0.98	-0.09	0.28	-0.15

The total explanatory power of two principal components was 81.05%, where principal component 1 and principal component 2 were 59.85% and 21.20%, respectively
SAM: soil organic matter; SAC: soil active organic carbon; STN: soil total nitrogen; SAP: soil available phosphorus; SAK: soil available potassium

Table 2. Soil nutrients of 60a plantation in principal component analysis in Mount Meng, China

	SAM	SAC	STN	SAP	SAK
Main component 1	0.94	0.09	0.89	0.91	0.67
Main component 2	0.19	0.96	0.12	-0.27	-0.18

The total explanatory power of two principal components was 80.81%, where principal component 1 and principal component 2 were 59.05% and 21.76%, respectively

SAM: soil organic matter; SAC: soil active organic carbon; STN: soil total nitrogen; SAP: soil available phosphorus; SAK: soil available potassium

Discussion

The differences of the surface soil nutrients in the forest are largely influenced by the types of vegetation. They are mainly reflected like this: plant litters and root exudates keep supplementing the surface soil nutrients and energy substances (Hedwall et al., 2015; Jia et al., 2005). Litter is an important structure and functional unit of material circulation and energy flow in the forest ecosystem (Jia et al., 2016). As the folia of needle-leaved trees have more lignin content (Wang et al., 2009) and relatively less leaf area than broad-leaved trees (Wang et al., 2004; Guo et al., 2006), the litter decomposition rate gets limited, thus influencing the nutrient return rate of litters. Some research shows that: when the stand age is the same, the soil of broad-leaved trees has more nitrogen than that of needle-leaved trees. It is thought that a large quantity of deciduous input and quicker litter decomposition rates could be used to explain why broadleaved trees are higher than needle leaved trees in terms of the topsoil fertility in the broadleaved deciduous forest (Jiang and Xu, 2006; Laganière et al., 2010). We suggest that for plantations with similar environmental backgrounds, *Pinus densiflora* are more suitable than *Pinus thunbergii* and *Quercus variabilis* in terms of maintaining soil nutrients when selecting tool species.

Conclusion

The research found that: when the stand age is 60 years, the content of organic matters, total nitrogen and rapidly available potassium was presented in a descending order: *Pinus densiflora* plantation > *Quercus variabilis* plantation > *Pinus thunbergii* plantation, and the content of active organic carbon was as follows: *Quercus variabilis* plantation > *Pinus densiflora* plantation > *Pinus thunbergii* plantation. The content of available phosphorus was as follows: *Quercus variabilis* plantation > *Pinus densiflora* plantation > *Pinus thunbergii* plantation. The research result relevant to *Pinus densiflora* plantation and *Quercus variabilis* plantation supported the first research hypothesis.

When the stand age of *Pinus densiflora* plantation changes from 30 years to 60 years, the content of surface soil nutrients all increased, including organic matters, active organic carbon, total nitrogen, available phosphorus and rapidly available potassium, where the content of organic matters, active organic carbon, total nitrogen, available phosphorus significantly increased. The research result relevant to *Pinus densiflora* plantation basically supported the second research hypothesis.

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