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Research Article

Soil Properties Responding to *Pinus tabulaeformis* Forest Thinning in Mountainous Areas, Beijing

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Abstract: Studied soil physiochemical properties of *Pinus tabulaeformis* plantations under varying silviculture intensity in shade, slope and thick soil areas in mountain areas of Beijing. The results show that at intensive (50%), medium (45%), weak (33%) thinning intensity compared with the control, (1) soil bulk density was reduced by 7.9, 5.7 and 3.9%, respectively in depth from 0 to 10 cm ($layer_{0-10}$) and soil properties in $layer_{0-10}$ were better than in depth of 10-20 cm ($layer_{10-20}$). (2) Total soil porosity increased by 7.3, 5.4 and 2.9%, respectively; the effects of thinning intensity on soil non-capillary porosity ranked as: weak>medium>intensive>control and the total soil porosity and non-capillary porosity both changed similarly in the two layers. (3) Water infiltration capacity and total soil pondage capacity were enhanced by thinning intensity. (4) Soil organic matter, total Nitrogen and rapidly-available Phosphorus were maximized in the medium thinning plot, while the rapidly-available Potassium was maximized in the intensive intensity plot, demonstrating that medium and intensive thinning can improve the *P. tabulaeformis* forest soil nutrient level. (5) The effects of thinning intensity on catalase and urease activities ranked as: medium>intensive>control>weak, which revealed that the soil enzyme activity can be improved by forest thinning. In conclusion, to improve soil physiochemical properties of *P. tabulaeformis* plantation in shade, slope and thick soil areas in mountain areas of Beijing, we prefer intensive thinning management.

Keywords: Forest thinning, principal component analysis, soil enzyme activity, soil nutrient level, soil organic matter, soil physical properties

INTRODUCTION

Forest soil plays an important role in forest water conservation (Zheng *et al*., 1997). The effects of silviculture on forest stands, especially forest soils, concern many aspects. Thinning forests will interfere with in different ways and the final conclusions regarding the effects of the thinning are inconsistent among existing studies (Li *et al*., 2003). For instance, thinning significantly affected soil fertility and increased the contents of soil micro-organisms and soil nutrient (Hu and Zhu, 1999). Soil microbial quantity, enzyme activity, total porosity, available nutrients and soil fertility were improved and soil bulk density were all reduced, after 2 year thinning in *Cunninghamia Lanceolata*, *Pinus massoniana*, *Fokienia hodginsii*, *Cryptomeria fortunei* and *Schima superba* (Zhang *et al*., 2001). The activities of phosphatase, chitinase and phenol oxidase were enhanced significantly in Loblolly Pine (*Pinus taeda*) forest soil after thinning (Boerner *et al*., 2006). Weak intensity thinning improved soil physiochemical properties, but under medium or intensive intensity, the soil condition was not significantly different from the control stand (Chi *et al*., 2006). Soil enzyme activities including catalase, urease, alkaline phosphatase, invertase and polyphenoloxidase were improved and enzyme activities in the A layer were more affected than those in the B and C, based on 5 years of *Pinus tabulaeformis* forest tending (Guo *et al*., 2007). The results of natural forest and Korean Pine (*Pinus koraiensis*) were slightly better than non-thinning area except Mongolian oak forest's (*Quecus mongolica*) through studying soil properties of the natural forests under different thinning intensities in east Liaoning Province. The soil chemical properties were improved to different levels and weak thinning intensity stand contained the largest soil microbial quantity (Sun, 2007). The 18 year thinning program in pine forests indicated that with enhanced thinning intensity, the forest soil total porosity, capillary moisture holding capacity, soil nutrient level and enzyme activities were significantly enhanced. It demonstrates that forest thinning can improve the forest soil quality (Yu *et al*., 2008). Thinning significantly improved soil alkaline phosphatase activity and other

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properties in *Platycladus orientalis* forests, especially in intensively thinned forests (Xu *et al*., 2008).

However, some research shows thinning did not significantly improve soil quality, even damaging soil structure. For instance, after 5 years of thinning a pine forest in northeast Germany, soil microbial activity was not significantly improved and soil enzyme activities including xylanase, phenol oxidase and peroxidase in both the organic layer and mineral layer were not significantly different from the control stand (Maassen *et al*., 2006). Forest soil nutrients in Larch-fir forest stands did not significantly change under <40% thinning intensity, indicating that long-term effects of thinning were not significant (Wang *et al*., 2009). With a 7 years thinning program, the activities of dehydrogenase, catalase, urease and phosphatase in soil were significantly reduced but protease activity did not change (Garcia *et al*., 1997). In *Pinus massoniana* forests, thinning reduced soil structure stability, soil total porosity, soil moisture storage capacity and holding capacity, but increased soil volume quality (Jing and Xiao, 1998).

Thinning disturbs surface soil including water, heat and other material redistribution. And soil properties will be changed corresponding to the method, time, intensity of thinning, forest types and other aspects (Li *et al*., 2003).

Pinus tabulaeform is one of the main planting species in Beijing. The existing area is 79,000 hm^2, accounting for 25% of the whole forest area in the city; the planted area is 61,000 hm^2 with 86% of young and half-mature trees (Ma *et al*., 2005). These forests play an important role in improving the ecological environment of Beijing.

This study is focused on a five-year thinning program of *P. tabulaeformis*e stands in mountainous areas in Beijing. We analyzed how soil physical properties changed before and after thinning. The results could help to manage and improve stand quality for young and immature stands in mountainous regions. In addition to potential stand quality improvements it could also allow for the study of protective effects of ecological public welfare forests.

Sample plots: The sample plots were located in Shui Zhang village, Mu Jia Yu town, Miyun district of Beijing (40° 25′N、116° 53′E), with elevation between 220-599 m and average annual temperature of 11.8°C. The annual average precipitation there was 623.0 mm, with 970.1 mm in rainy years and 285.3 mm in dry years and the precipitation of June-September accounted for more than 80% of the year's rainfall. The average annual evaporation was about three times of precipitation. Soil consisted of the leaching brown soil and mountain brown soil developed from sandstone and shale weathering slope, which were under varying degrees of long-term erosion. The soils consisted of coarse osseous characteristics, such as thin soil layers, hypoplasia structure, intensive gravel content and weak water retention capacity. The vegetation there is composed of shrubs, such as chastetree (*Vitex negundo* var. *Heterophylla*), wild jujube (*Ziziphus jujuba* var. *Spinosa* (Bunge) Hu), shrubby bushclover (*Lespedeza bicolor* Turcz), *Myripnois dioica* Bunge, *Spiraea* (*Spiraea trilobata* Lindl), patches of *Platycladus orientalis* and *Pinus tabulaeformis* plantations.

METHODOLOGY

Setting of sample plots: In April, 2004, the *P. tabulaeformis* plantation on shady thick soil slope was chosen owing to its representativeness (0.04 hm^2) for thinning operation. The target limbs to be cut off were mainly those with serious diseases and insect pests, or the overstocked trees and shrubs interfering with the growth and suitable density of *P. tabulaeformis*. Thinning intensity was divided into control (0%, C), weak (33%, W), medium (45%, M) and intensive (50%, I). Before the thinning operation, each sample plot was detailed surveyed in details, including breast height diameter of each trees, plot altitude, the position aspect and grade of slope, soil thickness and litter thickness. The statues of sample plot are shown in Table 1.

Measurement of soil physical properties and moisture holding capacity: Soil samples were collected before thinning in 2004 and 5 years after thinning in April, 2009, from depth 0-10 cm ($layer_{0-10}$) and 10-20 cm ($layer_{10-20}$) by digging out soil profile along the diagonal of each plot, with three repetitions in each sample. The formulas are as follows:

- Measuring soil bulk density by using loop-cuttig method, soil bulk density (g/cm^3) = dried soil weight/volume
- Soil total porosity (%) = [1-(soil bulk density/soil specific gravity)] ×100%, soil specific gravity: 2.65 g/cm^3
- Maximum moisture holding capacity (t/hm^2): W_t = 10000 $P_t h$, P_t is soil total porosity (%); h is soil thickness (m)
- Non-capillary moisture holding capacity (t/hm^2): W_0 = 10000 $P_0 h$, P_0 is for soil non-capillary porosity (%)

Table 1: Basic characteristics of *Pinus tabulaeformis* sample plots

Plot type	Label	Age/a	Altitude/m	Aspect	Grade	Density before thinning/hm^2)	Density after thinning (/hm^2)	Thinning intensity
Shady thick soil slope	I	38	125	N	27	3556	1734	50
Shady thick soil slope	M	38	125	N	31	3467	1956	45
Shady thick soil slope	W	38	125	N	27	3416	2289	33
Shady thick soil slope	C	38	131	N	27	3378	3378	0

Measurement of soil permeability: Soil permeability was measured by Bicyclic infiltration method. Sampling method and time were the same with Measurement of soil physical properties and moisture holding capacity. The calculation methods are:

- Initial permeability rate = Initial infiltration amount/initial infiltration time, in this research the initial infiltration time is 2 min.
- Steady infiltration rate is infiltration rate thinning to be stable in a unit time.
- Average infiltration rate is the average rate of water infiltration of the soils.
- Total amount of infiltration was for comparison. Because each plot had reached steady infiltration before 36, 36 min was taken as unified time.

Measurement of soil nutrient level: The measurement methods were: total Nitrogen, Kjeldahl determination; available Phosphorus, $NaHCO_3$ leaching with Molydenum- Antimony- D-iso-Ascorbic- acid-Colorimetry (MADAC); available Potassium, NH_4OAC leaching with flame photometer method (CACCSI, 1984). Sampling time was the same with Measurement of soil physical properties and moisture holding capacity and sampling depth was 5-10 cm, with three repetitions in each plot.

Measurement of soil organic matter and enzyme activity:
Organic matter: Potassium dichromate dilution heat method.

Soil urease: Indophenol colorimetric method. The steps are: get 10 g of air-dried soil sample screened by a 1-mm sifter, put into a 100-mL volumetric flask, add 2 mL toluene, place at room temperature for 15 min and injected in 10 mL of matrix (10% urea solution) and 20 mL of citrate buffer (pH 6.7). Blended carefully, put the flask into a constant temperature box at 37°C; for each group, set no-matrix soil (10 g soil+10 mL distilled water+and 20 mL citrate buffer) as control; the whole test was using soil solution (0 g soil+10 mL urea solution+and 20 mL citrate buffer) for comparison. After 24 h, add 38°C distilled water to the constant volume of 100 mL (toluene should float above scale line), then filter the solution and save the filtrate. Put 1 mL of filtrate in a 50-mL volumetric flask, immediately add 20 mL of distilled water, 4 mL of phenol sodium solution and 3 mL of sodium hypochlorite solution and shake up the flask. After 20 min when color changes, add to constant volume for colorimetry at 578 nm. Enzyme activity was represented by mg of amino Nitrogen per gram of soil hydrolysis generated.

Soil catalase: Titration method. The steps are: get 5 g of air-dried soil sample screened by the 1 mm sifter, put into a 150-mL triangular flask and add 40 mL of distilled water and 5 mL of 0.3% H_2O_2. Meanwhile, set a control by injecting 40 mL of distilled water and 5 mL of 0.3% H_2O_2 into a triangular flask without soil. Plug in the stopper and, put in a Dual-Action shaker at 120 rpm, for 30 min. Then inject 5 mL of 15 mol/L sulfuric acid to terminate reaction and filter the solution using quantitative filter paper. Get 25 mL of filtrate and titrate until slightly red using 0.1 mol/L $KMnO_4$ solution. The $KMnO_4$ solution (mL) represented enzyme activity within a unit weight of soil.

Data analysis: A data were analyzed using Least Significant Difference (LSD) multiple comparison on SPSS 16.0 (SPSS Inc., Chicago, US). Principal Component Analysis (PCA) was used to evaluate the comprehensive effect of thinning improvement on soil.

RESULT ANALYSIS

Effects of thinning on soil bulk density and porosity: Woodland soil is the main place in the forest to store water and the quantity and mode of soil moisture storage are strongly affected by soil physical properties (Yu and Wang, 1991). For instance, soil bulk density can directly affect the soil moisture storage capacity; soil total porosity can directly affect the soil air permeability and penetrating capacity; the non-capillary porosity can decide soil moisture storage quantity, the main aspect of forest soil moisture conservation and soil/water conservation function. This research determined the effects of different thinning intensities on the above three soil physical properties.

Effects of thinning on soil bulk density: To evaluate the effect of thinning on soil bulk density, we compared data before thinning and five years after thinning of *P. tabulaeformis* forests (Fig. 1). The results showed that soil bulk density was lower after thinning and decreased with improved intensity. Under thinning intensity W, M and I, the soil bulk density was reduced by 3.2, 6.1 and 10.3%, respectively in $layer_{0-10}$ and by 3.2, 7.4 and 15.3%, respectively in $layer_{10-20}$.

Five years after cutting, soil bulk density was lower in all the thinned forests. Under thinning intensity W, M and I compared to control, soil bulk density from 0-10 cm reduced by 3.9, 5.7 and 7.9%, respectively in $layer_{0-10}$ and by 3.5, 7.2 and 8.1%, respectively in $layer_{10-20}$.

The Analysis of Variance (ANOVA) showed that soil bulk density ranked as intensive<medium<weak <control intensity, which was negatively related with thinning intensity, after 5 years of thinning in the *P. tabulaeformis* forest. Comparisons of soil bulk density in intensively thinned plots in $layer_{0-10}$

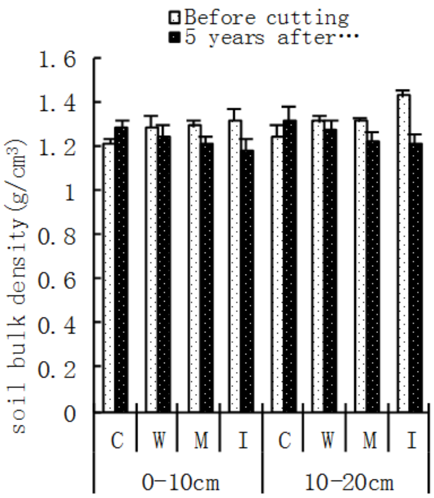

Fig. 1: Diversification of the soil bulk density of *Pinus tabulaeformis* before and after thinning

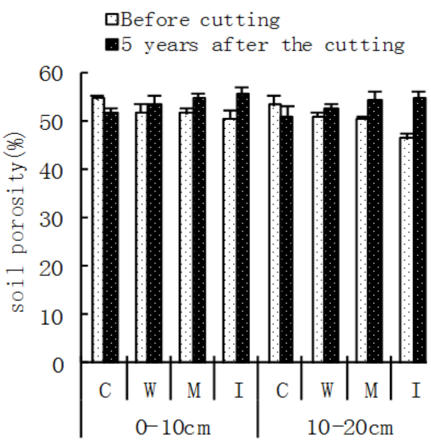

Fig. 2: Diversification of the soil porosity of *Pinus tabulaeformis* before and after thinning

were significantly different from weak intensity and control plots ($p<0.05$), but there was no significant difference among plots in layer$_{10\text{-}20}$ ($p>0.05$), indicating that soil bulk density was reduced 5 years after cutting, but not remarkably. These results showed that forest thinning significantly reduced the soil bulk density in *P. tabulaeformis* forests, which effectively improved the surface soil structure especially at depth 0-10 cm.

Effect of thinning forest on soil total porosity: To evaluate the effect of thinning on soil total porosity, we compared soil total porosity data collected from the *P. tabulaeformis* forest before and 5 years after cutting (Fig. 2). The results showed that after 5 years of forest thinning, soil total porosity was higher than before thinning and as the porosity increased more as foster intensity increasing. At intensity W, M and I compared with the control, the forest soil total porosity

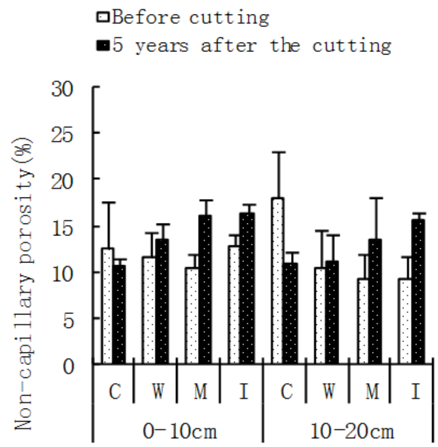

Fig. 3: Diversification of the soil non-porosity of *Pinus tabulaeformis* before and after thinning

increased by 3.0, 5.7 and 10.2% respectively in layer$_{0\text{-}10}$ and by 3.1, 7.2 and 17.8%, respectively in layer$_{10\text{-}20}$.

Five years after cutting, the forest soil porosity was higher than before. At intensity W, M and I compared with the control, soil total porosity increased by 2.9, 5.4 and 7.3%, respectively in layer$_{0\text{-}10}$ and by 3.4, 7.1 and 7.9%, respectively in layer$_{10\text{-}20}$.

Through investigating the soil porosity 5 years after cutting, we found that stand soil porosity increased after cutting, in positive relation to the thinning intensity: intensive>medium>weak>control. LSD analysis showed that soil total porosity was significantly improved in layer$_{0\text{-}10}$ ($p<0.05$) after thinning, but not significant in layer$_{10\text{-}20}$, indicating that thinning can improve soil at depth 0-10 cm more obviously than at depth 10-20 cm.

Effect of thinning forest on soil non-capillary porosity: To analyze the effect of thinning on the non-capillary porosity, we compared data collected from *P. tabulaeformis* forests before and 5 years after thinning (Fig. 3). The results showed that the non-capillary porosity was improved as thinning intensity increased. At intensity I, M and W, the non-capillary porosity increased significantly by 26.2, 49.6 and 52.5%, respectively in layer 0-10 (ANOVA, $p<0.05$); and increased by 2.8, 22.6 and 43.2%, respectively in layer 10-20, with ANOVA showing no significant difference between intensity levels. These results indicated that thinning has its greatest effect on non-capillary soil porosity at soil depths between 0-10 cm.

Meanwhile, comparing data after thinning with control, the non-capillary porosity of each thinning plot was obviously higher. At intensity W, M and I, the non-capillary porosity increased by 26.2, 49.6 and 52.5%, respectively in layer$_{0\text{-}10,}$; and by 3.0, 22.6 and 43.2%, respectively in layer$_{10\text{-}20}$.

ANOVA showed that the non-capillary porosity was positively related to the thinning intensity and the

Table 2: Soil infiltration of *Pinus tabulaeformis* before and after thinning

Permeability type	Depth (cm)	Control: Before 5 years	Control: After 5 years	Weak: Before	Weak: After 5 years	Medium: Before	Medium: After 5 years	Intensive: Before	Intensive: After 5 years
Initial permeability	0-10	3.595	2.167	10.225	4.335	0.515	7.267	2.932	9.945
rate (mm/min)	10-20	3.340	2.550	6.069	3.315	0.459	3.697	0.571	6.120
Steady infiltration	0-10	2.448	1.912	4.845	3.825	0.535	6.375	0.969	6.630
rate (mm/min)	10-20	2.703	2.422	4.284	2.805	0.663	3.060	0.490	4.845
Average infiltration	0-10	2.864	2.004	6.336	4.060	0.540	6.582	0.969	7.630
rate (mm/min)	10-20	2.991	2.477	4.720	2.996	0.643	3.315	0.490	5.202
Penetration amount	0-10	95.624	70.124	213.178	143.819	19.344	232.813	56.967	264.688
(mm)	10-20	101.336	87.974	162.077	104.039	23.256	115.259	17.931	181.559
Saturated hydraulic	0-10	1.632	1.275	3 .230	2.550	0.357	4.250	0.646	4.420
conductivity (mm/min)	10-20	1.802	1.615	2.856	1.870	0.442	2.040	0.326	3.230

non-capillary porosity increased as intensive>medium >weak>control. Multiple comparisons showed that the non-capillary porosity in layer$_{0-10}$ cm was significant ($p<0.05$), indicating that the non-capillary porosity improved after five years of thinning; but non-capillary porosity increased a little as intensive>medium> weak>control in layer$_{10-20}$, but not remarkable ($p>0.05$). This result indicated that the non-capillary porosity in layer$_{10-20}$ cm was improved less than in layer$_{0-10}$.

Effects on soil permeability: Soil infiltration capacity is one major factor of erosion and reflects hydrological evaluation standards of soil/water conservation vegetation and water conservation function (Zhang *et al*., 2009). The higher soil infiltration capacity means the rainfall can be infiltrated and stored by the soil in wooded areas faster, with less surface runoff and soil erosion become; on the opposite, erosion will be the surface runoff (Luo *et al*., 2004). In this test, five indexes including initial permeability rate, average infiltration rate, the steady infiltration rate and penetration amount and saturated hydraulic conductivity were used to evaluate soil infiltration capacity.

Forest soil permeability of each thinning plot was enhanced significantly after thinning ($p<0.05$). Under Intensive thinning (I), the five indices were improved by 2.4, 5.8, 2.9, 3.6 and 5.8 times, respectively in layer$_{0-10}$. Under Medium thinning (M), the five indices were improved by 13.1, 10.9, 11.2, 11.0 and 10.9 times respectively; however, no obvious change was observed under Weak thinning (W) or in the Control (C) ($p>0.05$). At depth 10-20 cm, the five indexces were obviously improved ($p>0.05$) by 9.7, 8.9, 9.3, 9.1 and 8.9 times, respectively at Intensive thinning (I) and by 7.1, 3.6, 4.2, 4.0 and 3.6 times respectively at Medium thinning (M); but no significant difference was observed at Weak thinning (W) or in the Control (C) ($p>0.05$).

The results among the thinned forests showed that: at layer$_{0-10}$, the five indices were higher than Control (C) by 3.6, 2.5, 2.8, 2.8 and 2.5 times, respectively at Intensive thinning (I) and were significantly higher by 2.4, 2.3, 2.3, 2.3 and 2.3 times respectively ($p<0.05$) at Medium thinning (M); no significant difference ($p>0.05$) was found at weak thinning or in the control. At depth 10-20 cm, all thinned forests were almost the same, without significant difference ($p>0.05$), which proved that thinning was beneficial for stand surface (0-10 cm) by improving permeability (Table 2).

Effects on soil moisture conservation amount: Woodland soil is the main place to store water. A study showed that the gravity water in the non-capillary pores plays the major role in adjustable storage in saturated moisture holding capacity (Hao and Wang, 1998). Therefore, forest soil moisture holding capacity mainly depends on the soil non-capillary pores and the quantity depends on the soil non-capillary porosity and soil thickness (Liu *et al*., 1996). Soil total storage is the sum of the water storage capacity of non-capillary and capillary pores. And the maximum of potential soil conservation reflects the potential storage, regulation ability and the soil moisture conservation ability as well (Wei *et al*., 2008).

The resulting effects of 5 years of thinning on the amount of water conservation (non-capillary moisture holding capacity) are shown in Table 3. Water conservation quantities in the samples from thinned forests at depths of 0-10 and 10-20 cm were increased following the thinning. In layer 0-20 cm under thinning intensity by W, M and I, water conservation quantities were generally increased by 12.2, 48.7 and 44.4%, respectively. Compared with the control, the amounts of water conservation were all higher in a positive correlation with intensity. Specifically, under thinning intensity W, M and I the water conservation quantities were increased by 14.4, 36.0 and 47.8%, respectively. ANOVA showed that thinning significantly changed soil moisture conservation quantity, especially after intensive and medium thinning ($p<0.05$), but not after weak thinning. These results indicated that intensive and medium thinning intensities were an effective measure to improve the soil moisture conservation quantity.

The resulting effect 5 years of thinning had on total soil moisture storage is showed in Table 3. Soil total

Table 3: Water conservation of *P. tabulaeformis* before and after thinning

Soil moisture holding capacity	Depth (cm)	Control 5 years before	Control After 5 years	Weak Before	Weak After 5 years	Medium Before	Medium After 5 years	Intensive Before	Intensive After 5 years	p value
Non-capillary water holding capacity (t/hm^2)	0-10	127.2	107.7	117.5	135.8	105.2	161.1	129.1	164.2	0.003**
	10-20	181.6	109.8	104.2	112.9	93.6	134.6	93.5	157.2	0.206
	Total	308.8	217.5	221.7	248.7	198.8	295.7	222.6	321.4	0.028*
Total water storage capacity (t/hm^2)	0-10	544.9	516.3	515.6	531.0	514.7	544.1	502.9	554.3	0.020*
	10-20	532.2	505.3	506.9	522.7	504.6	541.1	463.0	545.5	0.078
	Total	1077.1	1021.6	1022.5	1053.7	1019.3	1085.2	965.9	1099.8	0.015*

*: Significant difference at 0.05 level; **: Very significant difference at 0.01 level

Table 4: Soil nutrient of *Pinus tabulaeformis* before and after thinning

Soil nutrient	Control 5 years before	Control 5 years after	Weak Before	Weak 5 years after	Medium Before	Medium 5 years after	Intensive Before	Intensive 5 years after
Total nitrogen (g/kg)	3.075	2.587	2.252	3.138	4.035	6.698	4.166	5.961
Available phosphorus (mg/kg)	5.910	6.433	2.553	3.600	13.128	21.438	9.670	26.348
Available potassium (mg/kg)	15.146	16.032	17.070	23.224	18.249	25.760	14.334	22.819

Table 5: The organic matter and enzyme activity of *Pinus tabulaeformis* plantation before and after thinning

	Control 5 years before	Control 5 years after cutting	Weak Before	Weak 5 years after cutting	Medium Before	Medium 5 years after cutting	Intensive Before	Intensive 5 years after cutting
Organic matter (g/kg)	34.676	34.383	12.759	32.243	28.099	57.72	33.445	47.185
Urease (mg/g)	0.780	0.752	0.423	0.468	0.764	2.482	0.744	1.175
Catalase (mg/g)	0.488	0.603	0.398	0.563	0.437	0.643	0.474	0.910

storage capacities in both $layer_{0-10}$ and $layer_{10-20}$ were both higher than before. Total storage capacity under weak, medium and intensive thinning was enhanced by 3.1, 6.5 and 13.9%, respectively. Compared with the control, the total storages after 5 years were higher in a positive correlation with intensity. Specifically, under W, M and I intensity, total storages was increased by 3.1, 6.2 and 7.7%, respectively, with significant level in ANOVA ($p<0.05$). The intensive and medium cutting effectively improved the amount and the capacity.

Integrated analysis of the above data showed that thinning can enhance forest soil moisture holding capacity, because thinning greatly affected soil porosity. Soil moisture holding capacity and porosity are positively related. In considering thinning intensity levels, the most effective level was I cutting, followed by M cutting.

Effect on soil nutrients: Thinning is an important measure to adjust forest stand soil nutrients. Thinning can change forest community structure, species composition habitat conditions and affect the productivity and soil fertility status (Zhang *et al*., 2001). Soil nutrients levels are important indicators of the soil fertility, while understanding the soil nutrient element contents after thinning will be meaningful to promote benign nutrient circulation and maintain forest productivity (Fang *et al*., 1998). In this experiment, three indexes including total N, available P and available K were chosen to reflect the soil nutrient statuses before and after forest thinning.

Changes of soil nutrients: By comparing the pre and post thinning forest soil nutrient content in our plots we were able to see that; soil total N, effective P and K content ($p<0.05$) was increased in all plots. Five years later, the soil total N, effective P and K contents were improved by 43.1, 172.5 and 59.2%, respectively under Intensive thinning (I) and by 66.0, 63.3 and 41.2%, respectively under Medium thinning (M).

However, only the effective K content (23.224 mg/kg) was significantly increased under weak cutting (17.070 mg/kg) ($p<0.05$), while the other indicators were not significantly different ($p>0.05$) (Table 4).

Changes of organic matter and enzyme activity in forest soil: Organic matter is an important component of soil, as it affects and restricts soil properties. It is generally thought that soil organic matter content and soil quality are in positive correlation (Shimizu, 1994). Improving soil organic matter content can promote the formation of aggregates, thereby keeping their stability and thus, improving soil moisture holding capacity (Haynes *et al*., 1991). Organic matter is the energy of soil microbial activities, which can improve the microbial diversity and activity and soil physiochemical properties (Peverill and Judson, 1999). Meanwhile, organic matter can affect the quantity and speed of

Table 6: Initial eigen values

Principal component	Eigen value	Contribution rate/%	Cumulate contribution rate/%
F1	13.443	84.019	84.019
F2	2.053	12.833	96.853
F3	0.504	3.147	100.000

Table 7: Component matrix

Variable	The first component F1	The second component F2
Density	-0.978	0.091
Total porosity	0.978	-0.094
Non-capillary porosity	0.993	-0.093
Hydraulic conductivity	0.987	-0.143
Initial permeability rate	0.961	-0.273
Steady infiltration rate	0.987	-0.143
Average penetration rate	0.978	-0.203
36 min infiltration quantity	0.980	-0.194
Water conservation quantity	0.993	-0.093
Total storage capacity	0.978	-0.094
Total N	0.788	0.587
Available P	0.768	0.609
Available K	0.941	-0.190
Urease	0.637	0.766
Catalase	0.793	-0.396
Organic matter	0.824	0.567

nutrient transformation and directly affect the growth of vegetation, which is of great significance to the maintenance of soil fertility.

The soil organic matter contents (g/kg) before and after thinning showed that forest soil organic matter content increased by 41.1% from 33.445 to 47.185 g/kg after Intensive thinning (I), by 105.4 and 152.7% under Medium (M) and Weak (W) thinning respectively, without significant change in control plot ($p>0.05$) (Table 5).

Change of soil enzyme activity: Soil enzyme activity is an important indicator of soil fertility. Its change to a certain extent can reflect the evolution trend of forest soil quality and the effects of forest management measures on soil quality. This can provide certain guidance for maintaining forest health and formulating management methods (Geng *et al*., 2008). The experiment was based on the activities of urease and catalase, so as to know the changes before and 5 years after the forest thinning. Urease as a hydrolytic enzyme, can decompose organic matter and promote the hydrolysis of ammonia nitrogen and carbon dioxide, among which ammonia nitrogen is the direct source of trees (Bai *et al*., 2005). Catalase is widely distributed in soil and its activities can be used to analyze harm of H_2O_2 to plant growth (Dai and Wang, 1994). Its activity is related to soil respiration intensity and can reflect microbial activity intensity (Dai and Bai, 1995).

Comparing both urease and catalase contents before and after cutting, we found that: under Intensive thinning (I), soil urease and catalase contents increased by 57.9% from 0.744 to 1.175 mg/g and by 92.0% from 0.474 to 0.910 mg/g, respectively; under Medium (M), thinning two contents rose by 224.9 and 47.1% respectively; under Weak thinning (W) and in the Control (C), the two indicators did not change significantly ($p>0.05$).

Integrated evaluation of thinning effects on forest soil improvement: Because different thinning intensities affected the soil in many ways, the effects of thinning on soil improvement can be clarified should be studied in greater detail in order to maximize its efficiency. To do so it would be necessary to analyze the data of all indicators after 5 years thinning. This study chose SPSS 16.0 and PCA.

The averages of the indicators from different soil layers were used for analysis, including 16 indicators: density, total porosity, non-capillary porosity, hydraulic conductivity, initial permeability rate, steady infiltration rate, average penetration rate, 36 min infiltration quantity, water conservation quantity, total storage capacity, total N, available P, available K, urease content, catalase content and organic matter. The results are shown below.

In Table 6 cumulate contribution rate of the first two principal components (F1 and F2) reached 96.853%, indicating that calculation of F1 and F2 was quite reasonable, F1 contributed more to soil physical properties and F2 did more to soil chemical properties such as total N, available P, urease content and organic matter.

Using F1 and F2, weighted calculation of each stand integrated score was $L = 0.84019 * F1 + 0.12833 * F2$, where the weight was the contribution to each main factor (Table 7).

According to Table 8 the integrated scores of *P. tabulaeformis* forest were 0.93, 0.26, 0.09 and 1.11, under intensity control, weak, medium and intensive respectively. Clearly, after thinning *P. tabulaeformis* forest, the soil improvement was higher than the control, especially after intensive and medium thinning. Thus, it is better to use intensive cutting to improve soil for *P. tabulaeformis* forest.

Table 8: Principle components estimation of factor score

Intensity	Score			
	The first component F1	The second component F2	Integrated score	Order
Control	-1.068060	-0.266510	-0.93339630	4
Weak	-0.168320	-0.938500	-0.26214730	3
Medium	-0.112090	1.415573	0.08729141	2
Intensive	1.348467	-0.210560	1.10825221	1

CONCLUSION

Thinning improves soil physical properties: Thinning effectively reduced the soil bulk density and increased soil porosity and structure in *P. tabulaeformis* forest, especially in surface soil (0-10 cm) following intensive and medium thinning. Decreased forest canopy density, led to improved lighting conditions and light intensity in forested stands. This also led directly to speed up litter decomposition, resulting in increased soil humus content, which promoted the surface soil formation crumb structure and the soil's air permeability.

In addition, thinning measures also greatly improved the soil permeability and water retention capacity of *P. tabulaeformis* forested land (similarly, better in 0-10 cm), which was helpful to reduce surface runoff, increase infiltration of rainfall to soil and improve the ability of water conservation.

Thinning effectively improves the soil nutrients: The thinning effects on *P. tabulaeformis* soil nutrient content were different among the thinning intensities: effective P and K contents increased the most under intense thinning and total N content increased the most under medium thinning. Soil nutrients did not improve much as under weak thinning.

Soil organic matter content rose the highest 5 years of weak thinning (up to 152.7%) by 41.1% after intensive thinning and by 105.4% after medium thinning.

Furthermore, soil urease content and catalase content were increased the most by Medium thinning (M) and Intensive thinning (I) respectively.

Integrated evaluation of thinning effects on forest soil improvement: Following 5 years of varied intensity thinning on *P. tabulaeform* is forested stands; intensive thinning (50%) led to the greatest improvement of the forests' soil physiochemical properties.

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