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RESEARCH ARTICLE

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Soil properties in forest gaps and under canopy in broad-leaved *Pinus koraiensis* forests in Changbai Mountainous Region, China

Abstract The species composition and diversities, and soil properties under canopy gaps in broad-leaved *Pinus koraiensis* forests were studied in the Changbai Mountains. The results indicated that the species composition and diversities in gap were different from those under canopy. The Shannon-Wiener index, evenness index, and abundance index in gap were higher than those under canopy in the seedling layer, while the community dominance in the seedling layer increased in closed canopy. The physicochemical properties of soil changed with the change of space and resource availability in gaps. The thickness, standing crop, and water holding capacity of the litter layer under canopy were significantly ($p < 0.01$) higher than those in gap. The content of total nitrogen and total potassium of litter in gap were 10.47% and 20.73% higher than those under canopy, however, the content of total phosphorus and organic carbon under canopy were 15.23% and 12.66% more than those under canopy. The water content of 0–10 cm and 10–20 cm of soil layer in gap were 17.65% and 16.17% more than those under canopy. The soil buck density of 0–10 cm were slightly higher under canopy than that in gaps, but there was no significant difference in the soil buck density of the 10–20 cm soil layer. The soil pH values were 5.80 and 5.85 in gap and under canopy, respectively, and were not significantly different. The content of soil organic matter, total nitrogen, and total potassium in gap were 12.85%, 7.67%, and 2.38% higher than those under canopy. The content of NH_4^+-N, available phosphorus, available potassium, and total phosphorus in soil under canopy were 13.33%, 20.04%, 16.52%, and 4.30% higher than those in gap.

Keywords broad-leaved *Pinus koraiensis* forest, forest gap, litter layer, forest soil, Changbai Mountains

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1 Introduction

Forest gap refers to the discontinuous, bare forest land due to death of the dominant and co-dominant trees. Forest gaps provide potential space for forest regeneration and growth. It can be divided into top layer gap and extension layer gap (Watt, 1947). By changing the activities of microbiology and biological processes within and around it, gaps can dramatically change environment and resource availability for regeneration of different tree species (Zhang et al., 2001). Therefore, a great need appears to conduct an in-depth study on the characteristics of the microenvironment within forest gaps.

Many researches have been done around the world on the microenvironment within gaps. Zhang et al. (2001, 2001, 2002) discussed in detail the microenvironment under gaps of tropical rain forest and second-growth forest. Sha and Cao (1999) compared the soil nitrogen within gaps and under canopy of seasonal tropical rain forest. Geng et al. (2002) reported the soil and species conditions within gaps and canopy of planted conifer forest. Denslow et al. (1998) compared the NH_4-N, NO_3-N, PO_3-P for soils in gaps and under canopy of tropical forest. Arunachalam et al. (2000) conducted a comprehensive study on the microenvironment, soil microbiology, and soil nitrogen for subtropical humid broad-leaved forest.

Broad-leaved Korean pine forest is the dominant forest in the western Changbai Mountain region. Previous studies on forest gap under canopy of broad-leaved Korean pine mainly focused on gap structure and gap regeneration. Limited researches were done on soil characteristics within gaps. In this paper, the species composition, diversity, and soil physicochemical characteristics under canopy and gap were examined. The ultimate goal of this study is to provide a theoretical foundation for forest life cycle analysis.

2 Study site

The study area was located on the northern slope of the Changbai Mountain Conservation region. Under influence of seasonal wind, the climate in this region belongs to warm continental mountainous climate, dry and windy in spring, warm and rainy in summer, long and cold in winter. The average annual temperature is 3.3°C. August is the hottest month with an average temperature of 20.5°C and January is the coldest month with an average temperature of −16.5°C. Yearly highest and lowest temperatures are 32.3 and −37.6°C. Average annual rain precipitation is 600–900 mm. Soil type is dark brown forest soil 20 to 100 cm in depth, which is well drained on slow slope.

Korean pine forest is well known for its special species and diversity. Overstory species include: *Pinus koraiensis*, *Abies holophylla*, *Picea jezoensis*, *Tilia amurensis*, *Juglans mandshurica*, *Ulmus japonica*, *Acer mono*, *Betula costata*, *Fraxinus mandshurica*, *Phellodendron amurense*, *Betula platyphylla*, *Quercus mongolica*, *Acer mandshurica*, *Carpinus cordata* Blume, *Acer ukurunduense*, *Acer pseudosieboldianum*, *Tilia mandshurica,* and *Ulmus japonica*. *Pinus koraiensis*, *Picea jezoensis,* and *Acer mono* are the dominant species. Understory species include: *Philadelphus schrenkii* Rupr., *Deutzia amurensis* (Regel) Airy-Shaw, *Corylus mandshurica* and *Lonicera japonica* Thunb. Herb species include: *Brachybotrys paridiformis*, *Maianthemum bifolium*, *Phryma leptostachya*, *Carex* spp. and *Impatiens nolitangere*.

3 Methods

In August 2004, a line transect sampling method was employed and navigated with a compass; the investigation was carried out from south to north of the Korean pine forest close to the Changbai Mountain Ecological System Station. The gap size standard of 4–1,000 m^2 used in this study was the same as what Zang et al. (1999) described in their past study. A total of 20 gaps were investigated. All species within a 3 m range of the gap were recorded. For the overstory species with a height of over 1.3 m, their species, DBH, and height were recorded. For those with height below 1.3 m, only the heights were recorded. For the understory species, only species were recorded. The long and short axis of gaps and gap characteristics (species and rotten extent) were measured. The area of gaps was calculated as ellipses. The soil bulk density and water content of 0–10 cm and 10–20 cm soil layer were measured using the circular cutting method. Within the gap center area, four points were randomly selected, where surface soil samples were collected for laboratory analysis. Meanwhile, soil samples under canopy were also collected for comparison. For every gap and their surrounding canopy area, two sample spots were randomly selected. A 0.5 m × 0.5 m wooden frame was placed on a sample spot to collect foliages on the ground that were then dried at 105°C, weighted, and measured in terms of moisture content. Some other samples were dried at 60°C, ground, and sifted with 60 mesh sieves. After they were evenly mixed, the foliage samples were divided into four groups for further laboratory analyses.

Following the operation procedures of the China Soil Council (1999), the total N content was tested with the Kelvin Digestion method while the total P content was tested by decomposing sodium carbonate method. The total K content was tested by fusion with NaOH. The organic content was tested by exteriorly heating potassium dichromate–density method. The content of NH_4^+-N was tested by the indophenol blue colourimetric method. Available P content was tested by Hydrochloric Acid and effective K was tested using chemical extraction. Total N content in organic matter was tested by H_2SO_4-H_2O_2 distillation. Total K in organic matter was tested by H_2SO_4-H_2O_2 distillation.

Overstory with height less than 1.5 m was categorized as seedling. Overstory with height greater than 1.5 m and DBH less than 4 cm was classed as young tree. The overstory diversity was calculated on each layer. The following equations were used to calculate the species diversity index: Marglef abundance index $RI = (S-1)/\log_2 N$; Shannon-Wienner diversity index $H' = -\sum P_i \log_2 P_i$; Evenness index $E = H'/\log_2 S$; Dominance index $\lambda = \sum\left[n_i(n_i-1)\right]/\left[N(N-1)\right]$, where S is the number of species, i is the i^{th} species, N is the total number of species and $P_i = n_i/N$.

4 Results and analysis

4.1 Species composition and diversity index

After the gap was formed, a series of physical and biological environmental changes happened. Due to the difference of dominance and characteristics of different species, species composition and diversity index are different between gaps and under canopy forest (Zang et al., 1999, 2002; Geng et al., 2002). The overstory density is higher in gaps than those under canopy. A total of 27 and 29 species were recorded under canopy and in gaps, respectively. Also, there are differences among species composition. *Prunus padus* L., *Malus baccata* (L.) Borkh and *Maackia amurensis* Rupr. et Maxim. were the major species recorded under canopy; *Betula platyphylla* Suk., *Betula schmidtii* Regel, *Rhamnus davurica* Pall, *Syringa reticulate* (Blume) Hara var. *mandshurica* (Maxim.) Hara were the major species observed in gaps. Gaps not only influenced the overstory species composition and abundance index, but also affected the species composition and abundance index of understory and herb. The understory abundance index within gaps was bigger than that under canopy, 18 for under canopy understory and 23 for in gap understory. Understory coverage within gaps was higher than that under canopy. Among understory species, *Spiraea pubescens* Turcz. and *Vibrunum burejaeticum* Regel et Herder were mostly observed under canopy. *Rosa davurica* Pall., *Sambucus coreana* (Nakai) Kom. et Aliss, *Ampelopsis humulifolia* Bunge and *Rubus crataegifolius* Bge were mostly observed in gaps. The abundance index of herb within gaps was higher than that under canopy, 52 for under canopy and 60 for gaps. Within these herbs, *Aconitum kusnezoffii* Reichb., *Campanula punctata* Lam., *Polygonatum humile* Fisch. ex Maxim., *Epimedium brevicornum* Maxim. *Adenophora divaricata* Franch. et Savat, *Convallaria majalis* L. *Scutellaria pekinensis* Maxim., *Violar acuminate* Ledeb., *Astilbe chinensi*s (Maxim.) Franch. et Sav. ect. were mostly observed under canopy. *Pinallia ternate* (Thumb.) Breit., *Heracleum moellen dorffii* Hance, *Filipendula palmate* (Pall.) Maxim., *Caulophyllum robustum* Maxim., *Veratrum nigrum* L., *Ranunculus japonicus* Thunb. and *Cacalia komaroviana* ect. were mostly observed in gaps.

It was noticeable that the succession layer under canopy presented bigger Shannon-Wiener diversity index, Margalef abundance index, and Pielou evenness index than those in gaps (Table 1). Simpson dominance index demonstrated an opposite trend, higher in gaps than under canopy (Table 1). For regeneration layer, Shannon-Wiener diversity index, Margalef abundance index, and Pielou evenness index in gaps were higher than those under canopy. Higher Simpson dominance index was also presented under canopy. This means that gaps could have different effects in different layers. Generally, gaps can increase the species diversity of the succession layer and decrease the species diversity of the regeneration layer. There is no significant difference between dominance index in gaps and regeneration layer under canopy. But the dominance index of the succession layer under canopy was bigger than that in gaps. This is because part of the seedlings was dead due to competition when they developed from the regeneration layer into the succession layer. Compared to under canopy, more seedlings were dead in gaps, which made the distribution of individual tree even closer to each other within species.

Table 1 Comparison of species diversities in forest gaps and under canopy

Layer		H'	RI	E	λ
Sapling layer	Gap	1.227,3	1.236,1	0.733,3	0.365,2
	Canopy site	1.591,1	1.905,8	0.873,4	0.291,8
Seedling layer	Gap	1.230,1	1.314,4	0.764,7	0.346,9
	Canopy site	0.926,8	1.204,0	0.731,4	0.355,6

4.2 Comparison of characteristics of forest floor litters

Foliage layer as a special layer of forest soil is the main source of soil organic. Due to the opening of overstory, less litter was present on the ground. The more litter on the ground, the stronger the water holding capability. The different species composition and structure between gaps and under canopy cause the different composition of forest floor litter in gaps and under canopy (Zang et al., 1999, 2002; Zhu and Li, 2002; Bianba, 2004). Previous studies showed that the thickness, amount, water content of litter under canopy were significantly higher than those in gaps ($p<0.01$). Also, there was a significant positive relationship $r = 0.728$ ($p<0.01$) between litter amount and the water content in it. Total N and total K content in litter in gaps were 10.47% and 20.73% higher than those under canopy. Total P and organic C contents in litter under canopy were 15.23% and 12.66% higher than those in gaps (Table 2).

4.3 Comparison of soil characteristics

After gaps were formed, all root systems within gaps would die. Compared to under canopy, few live roots were noticed in gaps (Denslow et al., 1998; Ostertag, 1998), which causes less water to be lost due to the absorption of the roots. Also, gaps are covered with herbs whose entwined roots cause less water on the ground surface to be evaporated. Since the investigation was carried out during the rainy season, gaps have less overstory coverage, and rain can directly fall on the ground. For under canopy, part of the rainfall was stopped by the overstory, only a small part of the rainfall reached the ground. All of these reasons can cause soil in gaps containing more water than the soil under canopy. This study showed that for 0–10 cm and 10–20 cm soil layer, soil in gaps had 17.65% and 16.17% more water content than soil under canopy (Fig. 1).

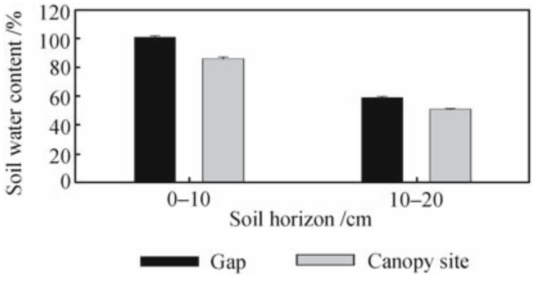

Fig. 1 Comparison of soil water content in forest gaps and under canopy

The change of sunlight condition causes the change of species and their composition in gaps. In gaps, the species composition is mostly shade-intolerant species (Canham, 1989). Under canopy, the stand is well covered by overstory, which causes less sunlight and less species of poor growth under canopy (Wang et al., 1980). In gaps, there are better sunlight conditions, which cause very good growth of herb species. Most litters in gaps were composed of broad leaves

Table 2 Comparison of characteristics of forest floor litters in forest gaps and under canopy

Position	Thickness /cm	Standing crop /($t\cdot hm^{-2}$)	Water-holding capacity /($t\cdot hm^{-2}$)	Total nitrogen content /($g\cdot kg^{-1}$)	Total phosphorus content /($g\cdot kg^{-1}$)	Total potassium content /($g\cdot kg^{-1}$)	pH	Organic carbon content /($g\cdot kg^{-1}$)
Gap	3.17 (0.23)	5.43 (0.48)	9.034 (1.15)	8.21(0.07)	3.70 (0.64)	2.23 (0.15)	6.34 (0.08)	254.21 (16.10)
Canopy site	4.56 (0.26)	7.49 (0.42)	13.24 (1.36)	7.44 (0.42)	4.26 (0.67)	1.87 (0.15)	6.41 (0.06)	286.41 (19.26)

Note: The values are the mean. The values in parenthesis are standard error.

Table 3 Comparison of soil nutrient in forest gaps and under canopy

Position	Total nitrogen content /(g·kg^{-1})	Total phosphorus content /(g·kg^{-1})	Total phosphorus content /(g·kg^{-1})	Ammonium nitrogen content /(mg·kg^{-1})	Available phosphorus content /(mg·kg^{-1})	Available Potassinum /(mg·kg^{-1})	Organic carbon content /(g·kg^{-1})	Organic matter /(g·kg^{-1})
Gap	7.72 (0.60)	0.93 (0.086)	12.49 (0.33)	90.19 (8.86)	10.08 (1.22)	151.32 (15.34)	176.8 (6.7)	304.7 (11.6)
Canopy site	7.17 (0.65)	0.97 (0.077)	12.20 (0.38)	102.21 (10.08)	12.10 (1.37)	176.32 (18.29)	156.6 (9.9)	270.0 (17.1)

Note: The values are the mean. The values in parenthesis are standard error.

and herbaceous substances that could be easily decomposed. Soil organic matter is the result of the decomposition of litters by soil fauna and microorganisms. The higher the temperature, the faster litters can be decomposed. All the decomposition rates were positively related to soil humidity (Swift et al., 1978). Gaps receive more sunlight, which increase the temperature and soil humidity (Arunachalam et al., 1996). Higher temperature and humidity increase the decomposition rate of litters, which can provide more organic substance in soil. The above reasons led to the increase of organic content of soil in gaps. Results showed that organic content of soil in gaps was 12.85% higher than that under canopy (Table 3).

The organic content in soil has a key effect on improving soil structure and physical characteristics. Due to the high content of organic matter of soil in gaps, the soil in gaps is more likely to produce rotten substance and aggregate structure, which will loosen the soil density. Our findings indicate that the soil density of 0–10 cm soil layer under canopy was slightly higher than that in gaps (7.92%). And for 10–20 cm soil layer, the density under canopy and in gaps had no significant difference (Fig. 2).

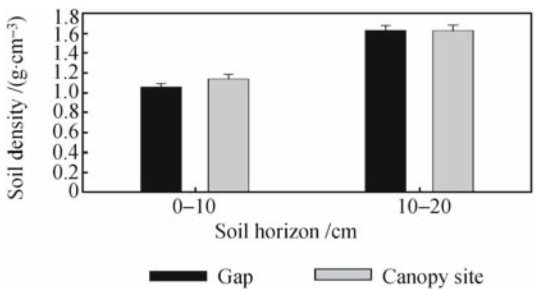

Fig. 2 Comparison of soil density in forest gaps and under canopy

The soil pH value has an important impact on the form and effectiveness of organic content, soil physicochemical characteristics, activities of microorganism, and biological growth. Most nutrient elements that are necessary for plant growth are related to the pH value. Foliage of broad-leaved trees contains more ash substance. After rotting, it will keep the soil slightly acidic or neutral. Most conifer foliage contain acid substances, which will cause the soil to have high acidic value after the leaves decompose (Geng et al., 2002). Results showed that the soil pH value in gaps was 5.80 and 5.85 for under canopy, which were not significantly different.

Organic matter is the main source of soil nutrition. Most N exists as organic matter in soil. The amount and distribution of N in soil is closely related to the organic matter in soil. The increase of organic matter content in soil can effectively cause an increase of total N amount in soil. The decomposition of foliages and dead roots would produce organic C that can effectively increase the total amount of multi-nutrient elements in soil. Results showed that total N and total K contents of soil in gaps were 7.67% and 2.38% higher than those under canopy, which was the same as the change of organic C (Table 3).

Soil microorganism and soil enzymes are the important components of soil. They directly play roles in organic decomposition, formation of rotten substance, nutrient conversion, and recycling (Zelles, 1999). Also the amount of soil microorganism and activities of soil enzymes have important effect on the process of effectiveness of soil nutrient (Yan and Liu, 1995; Xue et al., 2002). The activities of soil enzymes are significantly and positively related to the content of NH_4^+-N, available P and K (Cang et al., 1988; Yan and Liu, 1995; Zhao and Wang, 1995; Sun et al., 1997; Xu et al., 2000). The microorganisms in soil are closely related to the tree species and distance among roots (Pan et al., 1998). The existence of vegetation is helpful for improving the amount of microorganisms in soil. Soil near the roots are loose and well ventilated, and also contain more metabolic substances (Campbell and Greaves, 1990; Eiland and Gahonia, 1994; He, 1997). The activities of enzymes also show a horizontal distribution tendency. That is, activities are higher in soil with roots than soil without roots (Tian et al., 1999; Yao and Shu, 1999; Zhou et al., 2001; Zhong and Han, 2001). Due to the death of roots after gaps form, microorganism and activities of enzyme would be dramatically reduced. The available elements in soil will also be reduced dramatically. On the other hand, large amount of rainfall on the ground in gaps will bring about some of the available elements in soil. Our results showed that the content of NH_4^+-N, available P and available K in soil under canopy were 13.33%, 20.04%, and 16.52% higher than those in gaps, as was the same trend with the change of C/N in soil (Table 3).

After gaps form, the physicochemical characteristics of soil, decomposition and mineralization, the number and composition of soil animal, and soil microorganisms and enzymes in soil would be changed. These changes could cause complex changes of soil nutrient content. Soil under canopy contains slightly higher (4.30%) total P, which is probably due to the high amount of clay in soil (Pandey et al., 2000). Clay had very strong attractiveness to immobile P (Lee et al.,

Table 4 The correlation coefficient between gap size and soil characteristics

Soil pH	Soil ammonium nitrogen content	Soil water content		Soil density		Organic carbon content in litter	Total nitrogen content in litter
		0–10 cm	10–20 cm	0–10 cm	10–20 cm		
0.842**	−0.478*	−0.689*	−0.670*	0.649*	0.460*	−0.652*	0.524*

Note: **and * mean the significant correlation at $p < 0.01$ and $p < 0.05$ levels, respectively.

1990; Sha and Cao, 1999). The content of C/N in soil under canopy is 10.06% higher than those in gaps.

4.4 Gap size and soil characteristics

Gap size, an important index of forest gaps, reflects changes of the microenvironment in gaps. Gap size has an important effect on the effectiveness of temperature, moisture, and nutrients in gaps (Lee et al., 1990). There were correlated relationships among gap size and physicochemical characteristics of soil and litters (Table 4). Water content, content of NH_4^+-N, and organic C in litters were significantly and negatively related to gap size ($p < 0.05$). Soil density and total N content in litters were significantly and positively related to gap size ($p < 0.05$). Also, the soil pH value was significantly and positively related to gap size ($p < 0.01$).

5 Conclusions

1) There were significant differences among species and their composition under canopy and in gaps. Regeneration layer in gaps had higher diversity index and lower dominance index than those under canopy. Succession layer in gaps had lower diversity index and higher dominance index than those under canopy. These results are slightly different from the previous studies (Liu and Wu, 2002; Luo et al., 2002).

2) The thickness, amount, and water content of forest floor litters under canopy were significantly higher than those in gaps ($p < 0.01$). The contents of total N and total K in litters in gaps were 10.47% and 20.73% higher than those under canopy. The soil pH value in gaps was slightly lower than that under canopy. The total P and organic C in litter in gaps were 15.23% and 12.66% higher than those under canopy. Water content of soil in gaps was higher than that under canopy, which was 17.65% and 16.17% higher for 0–10 cm and 10–20 cm soil layer, respectively. The soil density for 0–10 cm layer under canopy was slightly higher than that in gaps (7.92%). For 10–20 cm soil layer, no significant difference was noticed. The soil pH value in gaps and under canopy was 5.80 and 5.85, which was not significantly different. Total N and total K contents of soil in gaps were 7.67% and 2.38% higher than those under canopy, which presented the same trend as the organic substance in soil. The contents of NH_4^+-N, available P, available K and total P of soil under canopy were 13.33%, 20.04%, 16.52%, and 4.30% higher than those in gaps.

3) Water content, content of NH_4^+-N of soil and organic C content in litters were significantly and negatively related to gap size ($p < 0.05$). Soil density and total N content in litters were significantly and positively related to gap size ($p < 0.05$). The soil pH value was significantly and positively related to gap size ($p < 0.01$).

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