Nutrient Distribution in *Picea likiangensis* Trees Growing in a Plantation in West Sichuan, Southwest China

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We measured nutrient distribution of *Picea likiangensis* (Franchet) E. Pritzel var. *balfouriana* trees growing in a plantation by field investigations, sample tree and plot harvest in West Sichuan, Southwest China. Based on the results in this study, the total biomass of plant compartments in plantation ecosystem was 114 829.1 kg ha^{-1}. Tree, shrub, herb, bryophyte and litter layers accounted for 93.9%, 0.9%, 0.02%, 0.04%, 5.2%, respectively. The total biomass of tree layers was 107 817.1 kg ha^{-1}. Needles, branches, stem wood, stem bark and roots accounted for 13.2%, 19.7%, 42.3%, 10.0% and 14.8%, respectively. The concentration of the nutrients was generally highest in the actively growing parts of the trees (e.g. needles) and lowest in the structural and not actively growing parts (e.g. stem wood). On the other hand, the concentrations of N, P, K and Mg were generally higher in the current year needles and branches than in the older needles and branches. These nutrient concentrations were also higher in the upper stem wood and bark than in the lower stem wood and bark, and in small roots than in large roots, whereas the opposite patterns were observed for the concentration of Ca in these compartments. The results will be helpful in understanding the nutrient behavior in a highly productive forest plantation and thereby providing decisive information for their sustainable management.

Keywords nutrient distribution, nutrient translocation, *Picea likiangensis*, plantation

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1 Introduction

During the past decade there has been a marked shift away from considering the forest as production systems for wood, towards realizing that the total organic production is important. Increased demand for forest products, the search for renewable resources or raw materials, and an increased concern for the well being of forest ecosystems are combined to stimulating studies on total forest biomass and nutrient dynamics (Madgwick et al. 1977, Grove and Malajczuk 1985, Pearson et al. 1987, Xue 1996, Chen 1998, Wang et al. 2000, Feldkirchner et al. 2003). These studies are important for providing information on nutrient budgeting of ecosystems (Turner 1986, Das and Ramakrishnan 1987, Ranger et al. 1997, Ingerslev 1999, Uri et al. 2003). On the other hand, nutrient translocation during the ageing of tissues is also an important mechanism for maintaining tree growth. Translocation of nutrients in foliage of trees during senescence has been intensively studied (Mead and Preston 1994, Zhang and Allen 1996, Saur et al. 2000, Zas and Serrada 2003), but studies dealing with nutrient translocation in other tree compartments are relatively few.

Picea likiangensis (Franchet) E. Pritzel var. *balfouriana* is one of the main constructive species of alpine and sub-alpine forest ecosystems in West Sichuan, Southwest China and distributes mainly in the upper reaches of Yangtze River. Since 1960s, large area of natural forest was cut down. The *P. likiangensis* plantation was planted later on, in order to prevent soil erosion, soil water loss and regulate climate, as well as retain ecological stability. So far, many ecologists have done research for alpine and sub-alpine coniferous forests in these regions, such as habitat traits, community attributes, ecological regeneration, relationship between forest regeneration and soil condition of slash and change of organic matter in soil (reviewed by Wang and Xu 1995, Liu 2002). However, relatively little is understood about the nutrient status of plantation ecosystems, particularly about nutrient distribution in dominant trees growing in a plantation.

In the present study, we measured nutrient distribution in *Picea likiangensis* (Franchet) E. Pritzel var. *balfouriana* plantations by field investigations, sample tree and plot harvest in West Sichuan, Southwest China. The objectives of this study were to: 1) determine the nutrient concentrations and nutrient contents of *Picea* tree components; 2) examine the age-related variation in the concentrations of various nutrients in needles and branches; 3) investigate the height-related variation in the concentrations of various nutrients in stem wood and bark; 4) test the diameter-related variation in the concentrations of various nutrients in roots. These results would be helpful in understanding the nutrient behavior in a highly productive forest plantation and thereby providing decisive information for their sustainable management.

2 Materials and Methods

2.1 Site Description

The site was situated at the Heishui forestry farm (32°25´N, 104°20´E, 3200 m alt.) in West Sichuan, Southwest China. Mean annual rainfall, temperature, maximum temperature and minimum temperature during 1970–2000 were 836.8 mm, 9.1 °C, 32.8 °C and –14.4 °C, respectively. The type of soil is mountain brown soil.

The stand was *Picea likiangensis* (Franchet) E. Pritzel var. *balfouriana* pure plantation whose even-age was 32 years, stand density 3460 trees per ha, canopy density 0.9, average height 10.5 m, average diameter at breast height (DBH) 10.4 cm, stem volume 125.2 $m^3\ ha^{-1}$, and stem volume growth 3.9 $m^3\ ha^{-1}\ yr^{-1}$. There were sparse shrubs under canopy, with a coverage of 20%, while bryophytes had a coverage of 80%. The main species of the shrub layer species were *Rubus amabilis, R. biflorus*, *R. flosculosus*, *Acanthopanax giraldii*, and *Similax trachypoda* etc., *Compositae* and *Poaceae* plants were the main species of the herb layer, *Hylocomium splendens*, *Pleurozium schreberi* and *Rhytidiadelphus triquetrus* were the main species of the bryophyte layer.

2.2 Field Experimental Design and Investigation

Three sample plots were chosen for the studies in August of 2001. The size of each plot was

0.2 ha, and plots were situated in a mid-slope position within the stand. Within each plot, tree height and DBH were measured on all trees. Average height and DBH, and density of the whole stand were then calculated. The total 9 trees were selected as sample trees representing different diameter classes in the plot. After falling the trees, all needles were separated from branches and sorted accordingly to 1, 2, 3, 4 and 5 (including > 5) years old, respectively. Stem bark was separated from stem wood in samples of every 2 m from the base of stems, respectively. All roots of the 9 sample trees were excavated and sorted into different root diameter classes $D \le 0.5$, $0.5 < D \le 1.0$, $1.0 < D \le 1.5$, $1.5 < D \le 2.0$, $D > 2.0$ cm. Fresh weight of all parts of the sample trees were determined in the field, then subsamples of all parts were oven-dried at 80 °C for 36 h to constant weight in the laboratory. The fresh weights of various parts were converted into dry weights using the respective fresh weight/dry weight ratios. According to the biomass of sample trees at the different classes and their density, the results on hectare basis then were calculated.

In addition, the biomasses of shrub, herb, bryophyte and litter layers were collected from 12 small plots (2 m × 2 m), at randomly located in the plot. All samples were individually weighed fresh in the field, then oven-dried and re-weighed to estimate their biomasses.

2.3 Nutrient Analysis and Calculations

All samples were ground to pass through a 20 mm mesh screen after drying at 80 °C for 36 h, respectively. Total N was determined by semi-micro Kjeldahl method, total P was determined colorimetrically by molybdate blue, and total K was determined by flame photometry. Ca and Mg were assayed by an atomic absorption spectrophotometer. These analyses were carried out at the laboratory of Sichuan Academy of Forestry. Nutrient concentrations were expressed as % of dry weight, and contents of plant compartments were then calculated with the SYSTAT statistical software package.

3 Results

3.1 Biomass and Nutrient Contents in Plantation Ecosystem

The height and DBH within plots varied from 8.8–12.2 m (average 10.5 m) and 8.5–12.3 cm (average 10.4 cm), respectively. The total biomass of plant compartments in plantation ecosystem was 114 829.1 kg ha^{-1}, tree, shrub, herb, bryophyte and litter layer accounted for 93.9%, 0.9%, 0.02%, 0.04%, 5.2%, respectively (Table 1). N,

Table 1. Mean and standard deviation (in parentheses) of nutrient contents in the different layers (kg ha^{-1}).

Layers	Biomass	Nutrient				
		N	P	K	Ca	Mg
Tree	107817.1 (11041.7)	322.7 (10.0)	81.3 (1.7)	239.8 (7.7)	253.4 (9.3)	32.5 (2.4)
Shrub	983.0 (84.9)	13.9 (1.3)	3.6 (0.3)	12.8 (0.6)	8.7 (0.6)	2.1 (0.2)
Herb	22.3 (1.2)	4.4 (0.7)	0.9 (0.2)	6.7 (0.5)	2.7 (0.2)	0.7 (0.1)
Bryophyte	50.8 (1.5)	4.8 (0.3)	1.7 (0.2)	1.9 (0.4)	5.4 (0.5)	1.5 (0.3)
Litter	5955.9 (191.4)	48.6 (2.1)	8.0 (1.9)	7.2 (0.6)	132.1 (8.3)	5.3 (0.3)
Total	114829.1 (11068.5)	394.4 (7.6)	95.5 (1.9)	268.4 (7.4)	402.3 (4.8)	42.1 (1.8)

Table 2. Mean and standard deviation (in parentheses) of nutrient contents in tree layer (kg ha^{-1}).

Compartments	Biomass	Nutrient N	P	K	Ca	Mg
Needle	14234.4 (1417.2)	126.0 (12.4)	17.4 (1.5)	48.1 (1.8)	70.9 (2.6)	9.1 (1.4)
Branch	21230.6 (1345.2)	64.4 (4.6)	21.6 (2.2)	81.2 (2.2)	68.7 (3.0)	8.3 (1.1)
Wood	45606.3 (2163.6)	63.1 (4.0)	17.3 (1.9)	50.2 (2.0)	21.9 (2.5)	5.0 (0.8)
Bark	10764.1 (1210.5)	46.7 (3.0)	16.5 (1.5)	40.4 (2.0)	67.8 (1.6)	7.9 (0.4)
Root	15981.7 (1808.4)	22.5 (2.6)	8.6 (1.2)	20.0 (1.4)	24.2 (2.3)	2.2 (0.5)
Total	107817.1 (7762.0)	322.7 (25.8)	81.4 (8.1)	239.9 (9.4)	253.5 (11.6)	32.5 (4.1)

Table 3. Nutrient concentrations of different compartments in tree layer. The data of needles and branches are calculated by weighting with the mass of each age (1, 2, 3, 4 and 5-year-old); the data of stem wood and bark are calculated by weighting with the mass of each height (0, 2, 4, 6, 8 and 10 m); the data of roots are calculated by weighting with the mass of each diameter class ($D \leq 0.5$, $0.5 < D \leq 1.0$, $1.0 < D \leq 1.5$, $1.5 < D \leq 2.0$ and $D > 2.0$ cm).

Compartments	Nutrient concentration (%) N	P	K	Ca	Mg	Total (%)
Needle	0.864	0.137	0.280	0.556	0.059	1.896
Branch	0.330	0.107	0.376	0.484	0.052	1.349
Wood	0.138	0.038	0.110	0.048	0.011	0.345
Bark	0.434	0.145	0.550	0.482	0.073	1.684
Root	0.300	0.088	0.244	0.400	0.035	1.067

P, K, Ca and Mg contents of plant compartments were 394.4, 95.5, 268.4, 402.3 and 42.1 kg ha^{-1}, respectively (Table 1). The total biomass of tree compartments was 107 817.1 kg ha^{-1}, needles, branches, stem wood, stem bark and roots accounted for 13.2%, 19.7%, 42.3%, 10.0% and 14.8%, respectively (Table 2). N, P, K, Ca and Mg contents of tree compartments were 322.7, 81.4, 239.9, 253.5 and 32.5 kg ha^{-1}, respectively (Table 2).

3.2 Nutrient Concentrations in Tree Compartments

Total nutrient concentrations in different tree compartments decreased the following order: needle > stem bark > branch > root > stem wood (Table 3). The concentrations of N, P, K, and Mg in needles and branches decreased with increasing age, while those of Ca increased (Figs. 1 and 2). The concentrations of N, P, K, and Mg in stem wood and bark increased with increasing stem height, while those of Ca decreased (Figs. 3 and 4).

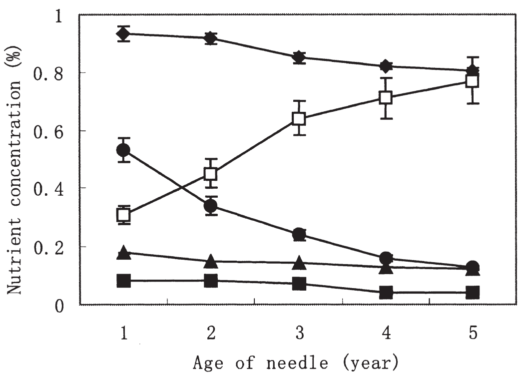

Fig. 1. Mean and standard deviation of N (♦), P (▲), K (●), Ca (□) and Mg (■) concentrations in the needles of different ages.

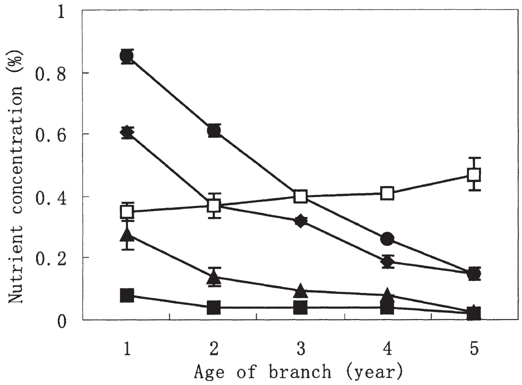

Fig. 2. Mean and standard deviation of N (♦), P (▲), K (●), Ca (□) and Mg (■) concentrations in the branches of different ages.

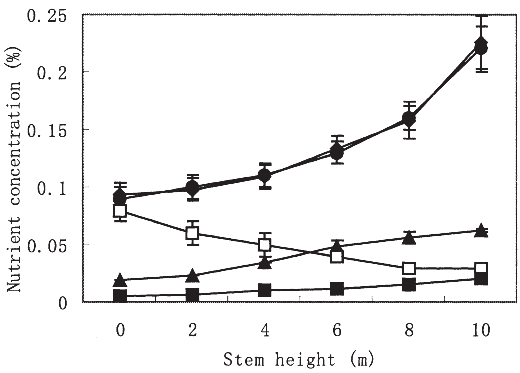

Fig. 3. Mean and standard deviation of N (♦), P (▲), K (●), Ca (□) and Mg (■) concentrations in stem wood at different stem heights.

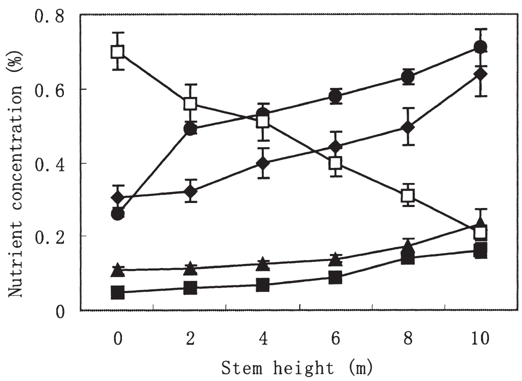

Fig. 4. Mean and standard deviation of N (♦), P (▲), K (●), Ca (□) and Mg (■) concentrations in stem bark at different stem heights.

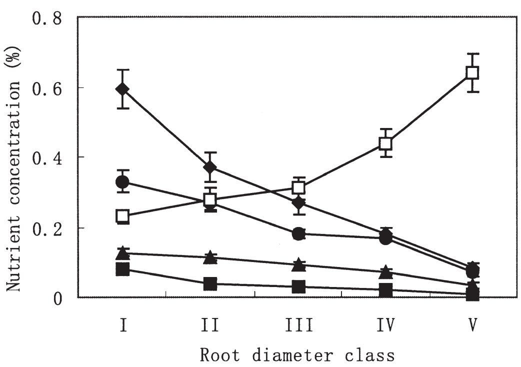

Fig. 5. Mean and standard deviation of N (♦), P (▲), K (●), Ca (□) and Mg (■) concentrations in the roots with different diameter classes (I, D≤0.5 cm; II, 0.5<D≤1.0 cm; III, 1.0<D≤1.5 cm; IV, 1.5<D≤2.0 cm; V, D>2.0 cm).

The concentrations of N, P, K, and Mg in roots decreased with increasing root diameter, while those of Ca increased (Fig. 5).

4 Discussion

The concentration of the nutrients was generally highest in the actively growing parts of the trees (e.g. needles) and lowest in the structural and not actively growing parts (e.g. stem wood). Similarly, data concerning nutrient distribution in the stem wood of several species show a sharp decrease in nutrient concentrations from physiologically active tissues to stem wood (Helmisaari and Siltala 1989, Colin-Belgrand et al. 1996). Changes in nutrient concentrations in different tissues similar to those observed in the present study have been reported for other woody plants (Braekke and Håland 1995, Wang et al. 1996, Wang and Klinka 1997, Chen 1998, Laclau et al. 2001). These results can be explained by the nutrient availability and the mobility within the trees.

If the studied 32-year-old stand were harvested, more nutrients would be removed from the sites if the entire aboveground trees were taken than if only the boles were removed. The nutrient drain rate of N, P, K, Ca and Mg by the former was 2.7, 2.2, 2.4, 2.6 and 2.4 times as much as by the latter. By combing data on tree height and condition of the existing stand, with knowledge of nutrient requirements of tree species, one can assess the probability that additional nutrient removals in a whole-tree harvest will prove detrimental to site productivity (Hendrickson et al. 1987, Wang et al. 1996, Chen 1998). Previous studies reported that nutrient removal from forest land reduced the growth of succeeding trees (Keeves 1966, Leaf et al. 1975, Wittwer et al. 1975). In some cases this has been proved to be due to nitrogen deficiency. The incidence of nutrient depletion can be expected to increase as more intensive forest management removes more nutrients through shorter rotations, and more complete tree utilization (Alban et al. 1978, Wang and Klinka 1997, Laclau et al. 2000, Zas and Serrada 2003). Therefore, our data provided support for the general practice of bole-only harvesting. Accordingly, we should plan to leave the branches with needles on the site so that nutrition of remaining trees or trees of next generation can be improved by reduced competition and the addition of nutrients to forest floor. For whole-tree utilization, the nutrient supplying potential of the site need to be quantified, and adjusted by species selection, fertilization, adjustment of rotation length, and other management strategies.

The concentrations of N, P, K and Mg were generally higher in the current year needles and branches than in the older needles and branches, these nutrient concentrations also were higher in the upper stem wood and bark than in the lower stem wood and bark, and higher in small roots than in large roots, whereas the opposite patterns were observed for the concentration of Ca in these compartments. Similar results have also been observed in previous studies (Cromer et al. 1985, Finer 1992, Grove et al. 1996, Ingerslev 1999).

Nutrient accumulation and distribution is a very efficient mechanism allowing tree growth in soil with limited nutrient resources. Relatively high nutrient demand of stands is satisfied for certain nutrients like N, P and K, both by uptake from soil and by internal translocations within tree itself, allowing a re-use of nutrients when tissues cease to be physiologically active. Nutrient translocation may be defined for the whole plant as the total amount of an element withdrawn from old tissues and transferred to new and growing tissues (Lim and Cousens 1986). It is based on a range of different physiological and biochemical processes: utilization of mineral nutrients stored in vacuoles, breakdown of storage proteins, or breakdown of cell structures and enzyme proteins thereby transforming structurally bound mineral nutrients into a mobile form (Marschner 1991). Nutrient translocation during the ageing of tissues is an important mechanism for maintaining tree growth in infertile soils (Saur et al. 2000, Laclau et al. 2001, Zas and Serrada 2003). Indeed, it may account for a significant amount of the nutrients required for annual biomass production and thus reduce the dependence of stands on soil nutrient reserves (Dierberg et al. 1986, Helmisaari 1992, Ranger and Colin-Belgrand 1996).

In conclusion, our data showed that nutrient concentrations were high in needles, low in stem wood, and intermediate in stem bark, branches and roots. Furthermore, concentrations of various nutrients, with the exception of Ca, tended to decrease with increasing needle and branch age, and increasing root diameter. These results suggested that *P. likiangensis* harvesting intensities could be manipulated to ensure that long-term yields were not compromised. In particular, leaving needles, branches and possibly bark on the site would minimize nutrient removal with little loss in product value.

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