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Biomass Accumulations and the Distribution of Nitrogen and Phosphorus within Three *Quercus acutissima* Stands in Central Korea

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Above- and belowground biomass and nitrogen (N) and phosphorus (P) distribution within three *Quercus acutissima* stands were investigated in central Korea. The average age (year) and diameter at breast height (DBH, cm) were 10.8 and 7.9 for Stand 1, 38.2 and 17.1 for Stand 2, and 44.0 and 20.7 for Stand 3, respectively. Fifteen trees were destructively harvested for dimension analysis of component biomass (stem wood, stem bark, foliage, branches, and roots) plus N and P concentrations. Total biomass (t ha^{-1}) was 88.7 for Stand 1, 154.9 for Stand 2, and 278.1 for Stand 3 while N and P contents in all tree components (kg ha^{-1}) were 483.3 and 52.2, 697.1 and 55.0, and 1113.9 and 83.7. Nitrogen concentrations were highest in the foliage, followed by the stem bark, branches or roots, and stem wood. In contrast, P concentrations were greatest in the roots, then foliage, branches, stem bark, and stem wood. In general, N and P concentrations in these components significantly decreased with tree age and DBH, while N and P contents significantly increased with age and size. These relationships were stronger for size than for age. Our current data could be utilized to estimate N and P budgets for silvicultural practices, including fertilization, thinning, and harvesting.

Keywords: allometric regression equation, nutrient concentration, tree age, tree size

Oak species (*Quercus* spp.) are the most dominant trees in the natural deciduous and mixed forests of Korea. They occupy a wide variety of ecological conditions and zones, from lowland warm temperatures to upper-montane conditions. This genus is an important source of wood and forest by-products, including acorns and mushrooms. The six most common species in Korea are *Q. aliena* Bl., *Q. acutissima* Carruth., *Q. dentata* Thunb., *Q. mongolica* Fisch., *Q. serrata* Thunb., and *Q. variabilis* Bl. In particular, *Q. mongolica*, *Q. variabilis*, and *Q. acutissima* are artificially planted because of their high economic value and wide distribution in the region (Korea Forest Service, 2005). This is why data on their biomass and nutrient distribution is necessary to improve our understanding of various ecological characteristics and to determine the management implications of that genus.

Although numerous researchers have investigated biomass and the production, distribution, and cycling of nutrients in oak forests, most of their studies have been focused on the aboveground components of *Q. mongolica* and *Q. variabilis* (Kim and Yoon, 1972; Lee and Park, 1986; Song and Lee, 1996; Lee and Kim, 1997; Park and Lee, 2001, 2002; Park et al., 2003; Son et al., 2004b). There is also limited information about biomass and nutrients associated with *Q. acutissima* (Chae and Kim, 1977; Lee et al., 1987; Park and Moon, 1994; Park et al., 1996). However, 11 to 23% of the total biomass as well as 20% of the total nitrogen are found in the belowground components (Son et al., 2004a). Furthermore, usually oak species are naturally regenerated after harvesting, so their stand structures are relatively uniform in terms of diameter distribution. Hence, more studies on biomass and nutrients, including belowground components, are needed for *Q. acutissima* of different ages within various types of stands. The objectives of our current study were 1) to develop allometric regression equations to estimate the biomass in above- and belowground components, and 2) to determine nutrients distribution among components, including the roots, in *Q. acutissima* stands of different ages in central Korea. We focused on nitrogen (N) and phosphorus (P) because they are most commonly limiting in that region (Kim, 1998; Son et al., 2004b).

MATERIALS AND METHODS

Study Site

This study was conducted on three pure *Quercus acutissima* stands, each of relatively uniform age, within a forest near Chungju-si, Chungcheongbuk-do (Chungbuk) (Table 1). Stand 1 was young, Stands 2 and 3 were relatively mature, and their understories were dominated by *Symplocos chinensis* for *pilosa*, *Styrax obassia*, *Q. mongolica*, and *Q. variabilis*. These stands had been naturally regenerated after the mixed oak forests were harvested. Stands 2 and 3 were 100 m apart, and Stand 1 was about 10 km away from the others. In that region, the average annual temperature and precipitation are 11.2°C and 1381 mm, respectively, with about 70% of that precipitation falling between June and August. Three 10 × 10 m plots were randomly located within each stand, and

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Table 1. Characteristics of *Quercus acutissima* stands in central Korea. Ranges are in parentheses.

	Stand 1	Stand 2	Stand 3
Location	37° 03′07″ N, 127° 55′45″ E	37° 07′24″ N, 127° 58′47″ E	37° 07′25″ N, 127° 58′42″ E
Elevation (m)	92	407	415
Aspect	SW	SE	SE
Slope (°)	3	37	40
Age (yr)	10.8 (8-12)	38.2 (34-43)	44 (41-46)
DBH (cm)	7.9 (2.2-17.2)	17.1 (6.0-27.6)	20.7 (8.0-41.5)
Density (trees ha^{-1})	2,100	800	733

diameters at breast height (DBH) for all overstory vegetation were measured in August of 2005 (Table 1).

Allometric Regression and Biomass Estimation

Site-specific allometric regression equations were developed using the destructive analysis method (Whittaker and Marks, 1975). In late August 2005, 15 trees that represented the whole range of diameters in the three stands were randomly sampled outside the plots. The probability that a tree from a particular diameter class would be selected for dimensional analysis was proportional to the diameter frequency. Trees were cut at the soil surface, branches were removed, and the stem was cut into 2-m sections and weighed. Basal discs were removed from each stem section to determine separate dry weights for their bark and their wood. These weights were then summed for the entire tree and related to DBH using regression equations. Branches were weighed separately from their foliage, and the dry weights of those two components also were related to DBH. Finally, 7 of the 15 harvested trees were selected based on diameter distribution for the three stands, and all their roots were excavated. After those roots were washed lightly to remove soil particles, they were oven-dried. Logarithmic regressions of tree-component biomass (stem wood, stem bark, foliage, branches, and roots) as a function of DBH were calculated as $\log Y = a + b \log X$. To correct for bias in the log-transformed allometric equations, we used Sprugel (1983) correction factors (Son and Kim, 1998).

N and P Contents

Sub-samples (15 for the stem wood, stem bark, foliage, and branches plus 7 samples for the roots) were collected from harvested trees. All were then dried and ground with a laboratory mill. Afterward, they were digested according to a sulfuric acid method (Son and Gower, 1992), N and P concentrations were analyzed colorimetrically with a Lachat continuous flow ion analyzer (Lachat QuickChem AE, USA). Nitrogen and P contents were determined by multiplying their concentrations per component by the sample dry weights. Differences in biomass, N and P concentrations, and N and P contents among tree components and stands were analyzed with a general linear model procedure. Regression analysis was used to examine the relationship between N and P concentrations and/or contents and tree age and/or tree size. All statistical analyses were performed with SAS (2004).

RESULTS AND DISCUSSION

Biomass

The biomass values for stem wood, stem bark, branches, foliage, and roots of *Q. acutissima* were nonlinearly related to stem diameter (Fig. 1), which explained over 95% of the variance in all cases except for foliage (Table 2). All correlations of the logarithmically transformed values were highly significant ($p < 0.001$), and mean square residuals (S_{yx}^2) were generally small. The correlation was highest for total biomass ($R^2 > 0.99$) compared with individual components. Correction factors ranged from 1.002 to 1.019 (Table 2). Others have also reported that DBH accounts for a large portion of the variation in tree-component biomass for this species (Park and Moon, 1994; Park et al., 1996). Interestingly, slopes of allometric regressions from our study were very similar to those from other studies of the same species; however, their intercepts were quite different (Park and Moon, 1994; Park et al., 1996). Various biotic and abiotic environmental factors might influence these differences, so one could infer that regression equations to estimate biomass should be carefully applied when used in areas outside of where they were developed (Son et al., 2007).

Based on the equations from Table 2, total above- plus belowground biomass (t ha^{-1}) was 88.7 for Stand 1, 154.9 for Stand 2, and 278.1 for Stand 3 (Table 3). These values were comparable to those for temperate deciduous forests (100 to 500 t ha^{-1}; Rodin and Bazilevich, 1967), temperate deciduous oak species (40 to 240 t ha^{-1}; Kimmins et al., 1985), and the major deciduous oak species in Korea (31.3 to 438.0 t ha^{-1}; Son et al., 2004b). In particular, the biomass values for Stands 1 and 2 were very close to those previously reported for similarly aged *Q. acutissima* forests (Chae and Kim, 1977; Park and Moon, 1994; Park et al., 1996).

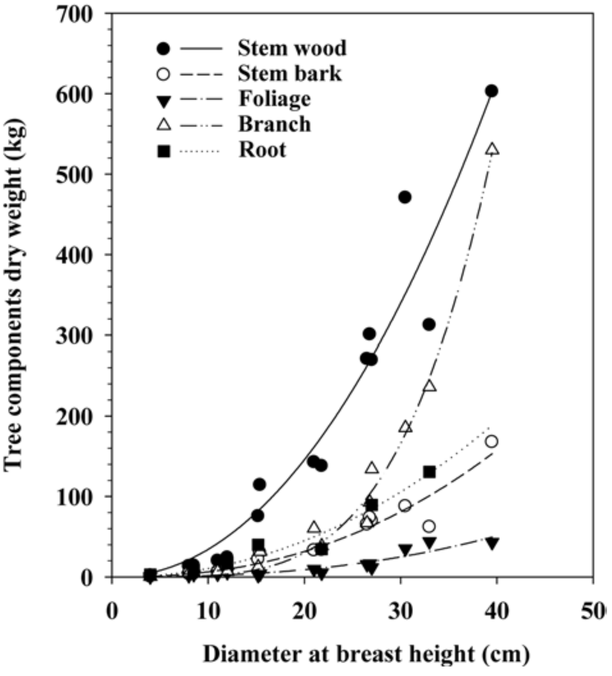

Figure 1. Relationships between diameter at breast height (cm) and tree component dry weight (kg) for *Q. acutissima*.

Table 2. Regressions for tree component dry weight (kg) on diameter at breast height (cm) for *Q. acutissima* in central Korea. Equations follow the form log Y = a + b log X, where X is stem diameter and Y is component dry weight. CF is a correction factor (Sprugel, 1983).

Component	A	B	S_{yx}^2	R^2	CF
Stem	-1.090	2.525	0.010	0.978	1.005
Stem wood	-1.219	2.549	0.011	0.978	1.005
Stem bark	-1.662	2.428	0.011	0.974	1.006
Branch	-2.116	2.908	0.021	0.967	1.010
Foliage	-1.489	1.897	0.038	0.871	1.019
Aboveground total	-1.009	2.574	0.007	0.986	1.003
Root	-0.634	1.772	0.011	0.962	1.005
Total biomass	-0.607	2.305	0.003	0.993	1.002

Table 3. Biomass (t ha^{-1}) by tree component for *Q. acutissima* in central Korea.

Location	Age (yr)	Stem wood	Stem bark	Branch	Foliage	Root	Total	Reference
Chungbuk	8-12 (Stand 1)	39.1	10.5	12.1	4.3	22.7	88.7	This study
Chungbuk	34-43 (Stand 2)	64.1	21.2	32.3	6.3	31.1	154.9	This study
Chungbuk	41-46 (Stand 3)	137.3	33.2	58.0	8.6	41.0	278.1	This study
Kyunggi	29	151.7		32.1	5.4	60.7	249.8	Lee et al., 1987
Chunnam	26-29	81.8	18.0	31.6	8.7	23.9	164.0	Park and Moon, 1994
Kyunggi	12-14	52.2		12.0	5.3	17.4	86.8	Chae and Kim, 1977
Kyunggi	38	94.8		26.0	1.9	-	122.7	Park et al., 1996

However, our value for Stand 2 was lower than that of 249.8 t ha^{-1} from a 29-year-old *Q. acutissima* forest (Lee et al., 1987).

For the relatively mature stands (2 and 3), biomass was distributed as follows: stem wood > branch > root > stem bark > foliage; while root biomass was higher than branch biomass from the young Stand 1 (Table 3). This distribution of biomass among tree components was similar to that reported earlier for the same species in Korea (Chae and Kim, 1977; Park and Moon, 1994; Park et al., 1996). As stands develop, their relative proportions of tree components change, with that of foliage generally decreasing and that of stems increasing over time (Waring and Running, 1998). Here, the respective ratios of foliage or root biomass to total above- plus belowground biomass were 4.8 and 25.6% for Stand 1, 4.1 and 20.1% for Stand 2, and 3.1 and 14.7% for Stand 3. These ratios decreased with stand age, although the relationships were not statistically significant ($R = -0.90$, $p > 0.05$ for foliage; $R = -0.90$, $p > 0.05$ for roots). However, the contribution of stems plus branches to the total biomass significantly increased with stand age ($R = 0.94$, $p < 0.05$). Similar relationships have been found for different oak species in this study region (Son et al., 2004b). Moreover, the relative amount of fine roots is known to decrease with stand age (Vanninen et al., 1996). In our study, however, this was not examined because we did not separate them from the rest of the root mass.

Vegetation N and P Contents

Nitrogen concentration was highest in the foliage, followed by stem bark, branches or roots, and stem wood, while P was more abundant in the roots, followed by foliage, branches, stem bark, and stem wood (Table 4). Except for our values for root P, these component levels of N and P were generally similar to those for temperate deciduous oak species (Kimmins et al., 1985) and for *Q. variabilis* and *Q. mongolica* in central Korea (Son et al., 2004a). In particular, the N concentrations in Stand 1 were very close to those measured from 12- to 14-year-old *Q. acutissima* growing in central Korea (Mun et al., 1977). However, our root-P concentrations were much greater than found in mature *Q. variabilis* and *Q. mongolica* (Son et al., 2004a) or young *Q. acutissima* (Mun et al., 1977). The reason for that is unclear.

Table 4. Nitrogen and P concentrations (%) by tree components for three *Q. acutissima* stands. One standard error of the mean is in parentheses. Values not followed by the same letter indicate significant differences among stands ($p < 0.05$).

Component	Stand 1		Stand 2		Stand 3	
	N (%)	P (%)	N (%)	P (%)	N (%)	P (%)
Stem wood	0.28a ± 0.02	0.025a ± 0.001	0.22ab ± 0.03	0.006b ± 0.002	0.19b ± 0.01	0.004b ± 0.002
Stem bark	0.61a ± 0.06	0.020a ± 0.003	0.55a ± 0.03	0.011b ± 0.001	0.56a ± 0.06	0.012b ± 0.003
Branch	0.39a ± 0.02	0.041a ± 0.002	0.41a ± 0.01	0.017b ± 0.002	0.45a ± 0.04	0.025b ± 0.005
Foliage	2.05a ± 0.06	0.108a ± 0.003	2.01a ± 0.08	0.071c ± 0.004	2.10a ± 0.03	0.084b ± 0.003
Root	0.57a ± 0.05	0.135a ± 0.010	0.37b ± 0.02	0.117a ± 0.002	0.55ab ± 0.00	0.128a ± 0.000

In our study, the root masses were not separated into fine and coarse components. Therefore, it is possible that total P concentrations might be influenced by the proportion of fine roots, which commonly have higher P values than do the coarse roots or the total mass (Millikim and Bledsoe, 1999).

Nitrogen concentrations in the stem wood and roots differed significantly among our three stands, as did the P concentrations in all the aboveground components ($p < 0.05$) (Table 4). Although it is commonly recognized that nutrient concentrations are higher in smaller and younger trees than in larger and older trees, the effects of tree size and age are poorly understood (Cho and Kim, 1989; Yi, 1998; Rytter, 2002). Here, N and P concentrations in the stem wood from young Stand 1 were significantly greater than those from the mature Stands 2 and 3. Consequently, there were significant correlations between component N and P concentrations and age (Fig. 2). However, it should be noted that those ages were not equally distributed in this study. Therefore, for N, the relationship between nutrient concentration and tree age was significant only for stem wood ($R = -0.66$, $p < 0.01$) while for P relationships were always significant except for the roots ($R = -0.89$, $p < 0.001$ for stem wood; $R = -0.60$, $p < 0.05$ for stem bark; $R = -0.69$, $p < 0.01$ for branches; $R = -0.75$, $p < 0.01$ for foliage). These results were consistent with those from other studies (Cho and Kim, 1989; Helmisaari and Siltala, 1989; Rytter, 2002), where the average nutrient concentrations in the stems of hybrid aspen, Scots pine, and Korean pine were found to decline with increasing age. Turvey and Smethurst (1994) also have shown that N and P concentrations in the needles decrease over time for *Pinus radiata*. In addition, we observed that nutrient concentrations changed with tree size, as represented by DBH; there were highly significant relationships between N concentration in the stem wood and DBH ($R = -0.69$, $p < 0.01$) as well as between DBH and the P concentrations in stem wood ($R = -0.81$, $p < 0.001$) and branches ($R = -0.56$, $p < 0.05$) (Fig. 3). Madgwick and Mead (1990) have noted that nutrient (N, P, K, and Mg) concentrations are curvilinearly related to stem diameter in *P. radiata*. However, Rytter (2002) found no such relationship in hybrid aspen. Nonetheless, our results suggest that more nutrients are removed via silvicultural operations, including thinning or harvesting, from younger and smaller trees than from those that are older and larger.

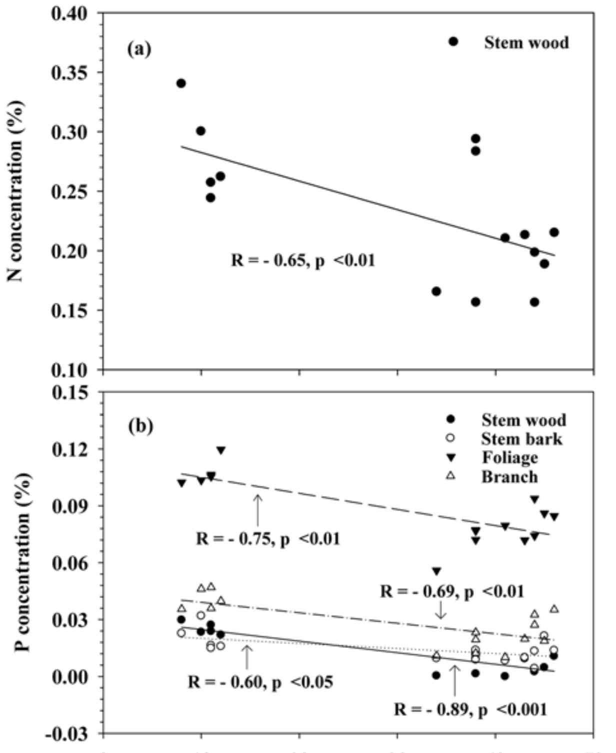

Figure 2. Relationships between tree age and N (**a**) and P (**b**) concentrations in tree components of *Q. acutissima*.

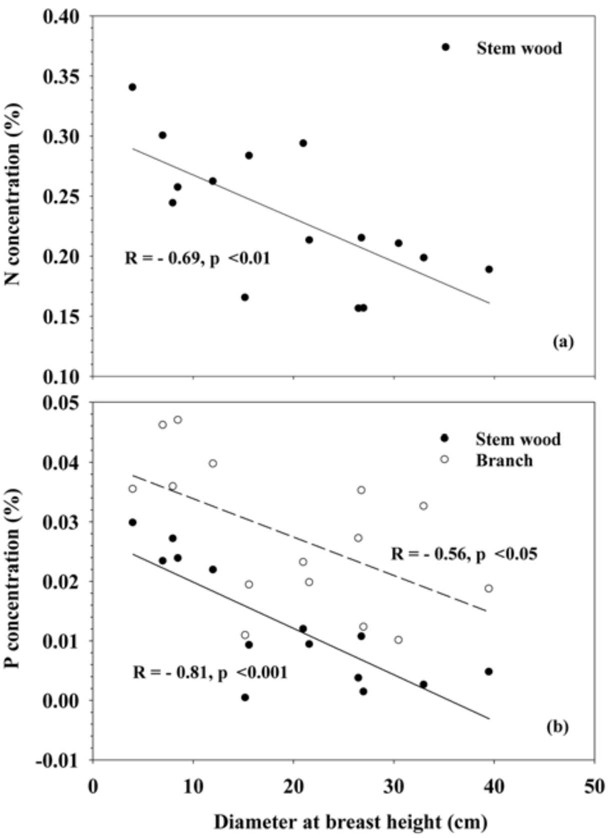

Figure 3. Relationships between diameter at breast height (cm) and N (**a**) and P (**b**) concentrations in tree components of *Q. acutissima*.

Stand 3 had the highest total N and P contents (for both above- and belowground components) (1113.9 and 83.7 kg ha^{-1}), followed by Stand 2 (672.2 and 55.0 kg ha^{-1}) and Stand 1 (483.3 and 52.2 kg ha^{-1}) (Fig. 4). These values were within the ranges for temperate deciduous forests (530 to 1200 kg ha^{-1} for N and 40 to 100 kg ha^{-1} for P) as measured by Rodin and Bazilevich (1967), and for Korean deciduous oak forests (280 to 1623 kg ha^{-1} for N and 26 to 360 kg ha^{-1} for P) as reported by Son et al. (2004b). Total N and P contents for our 38-year-old Stand 2 were lower than those for a 29-year-old *Q. acutissima* forest in Kyonggi (1073.1 and 140.5 kg ha^{-1}; Lee et al., 1987). Likewise, the N and P contents for our 11-year-old Stand 1 were higher

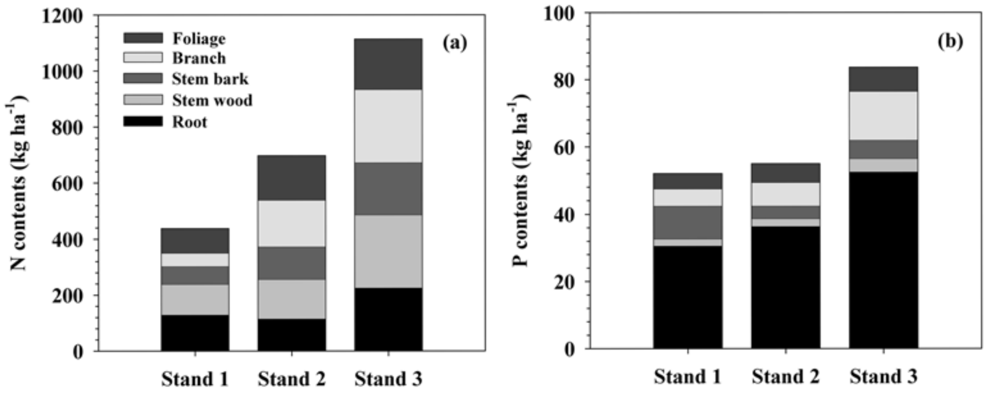

Figure 4. N (**a**) and P (**b**) distributions among tree components for three *Q. acutissima* stands.

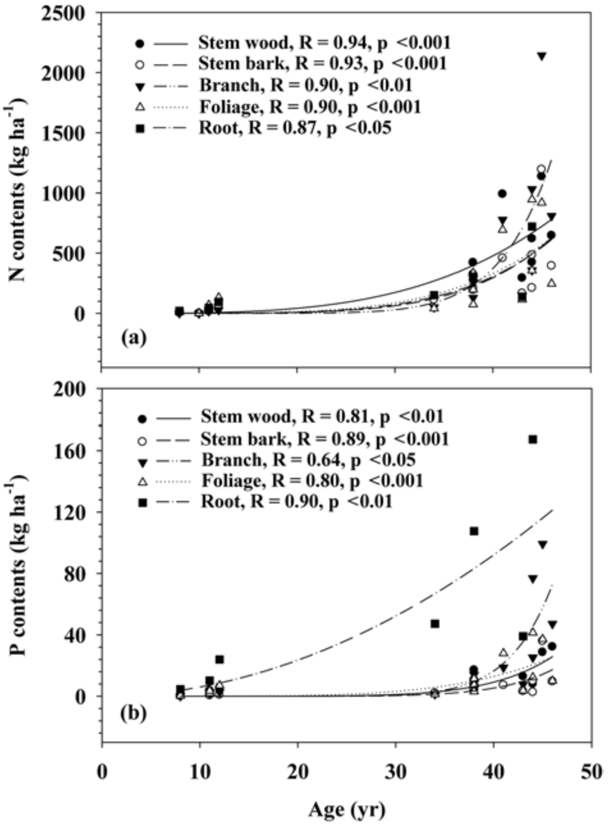

Figure 5. Relationships between tree age and N (**a**) and P (**b**) contents in tree components of *Q. acutissima*.

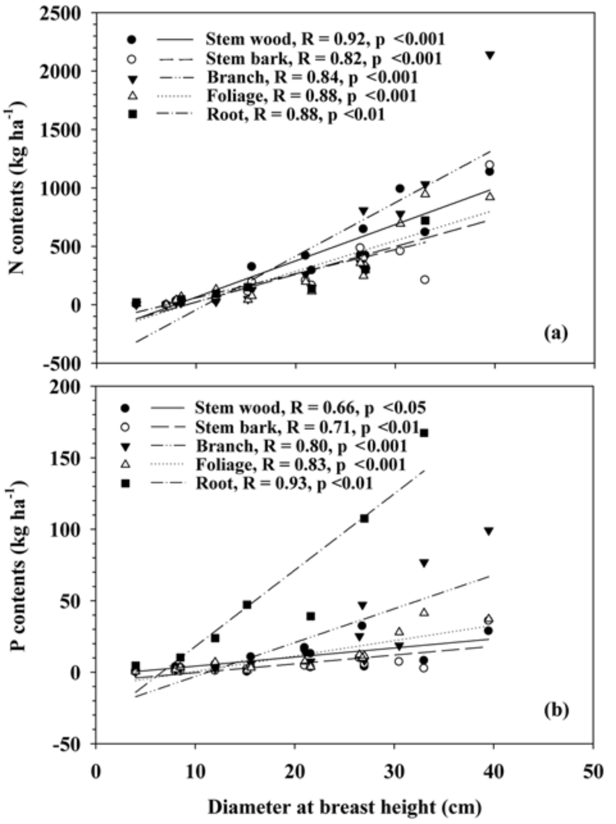

Figure 6. Relationships between diameter at breast height (cm) and N (**a**) and P (**b**) contents in tree components of *Q. acutissima*.

than those for a 12- to 14-year-old *Q. acutissima* forest in Kyonggi (279.5 and 21.9 kg ha^{-1}; Mun et al., 1977). The stem (wood plus bark) accounted for the greatest amount of nitrogen while the roots had the most phosphorus. Although foliage made up 3.1 to 4.8% of the total biomass, it contained 16 to 23% of all the N and 9 to 10% of the total P compared with other organs (Regina, 2000).

Nutrient concentrations in our tree components decreased with age while the component biomass values simultaneously increased (Fig. 2; Table 3). Consequently, we found significant positive relationships between tree age and N and P contents for all components ($p < 0.05$) (Fig. 5). These patterns were consistent with results described for young and mature coniferous species in this study region (Cho and Kim, 1989; Yi, 1998). In addition, N and P contents in all tree components were strongly and positively correlated with DBH (Fig. 6). The ratio of increase with size varied among components for N and P; N contents in the branches and stem wood appeared to increase rapidly with size, likewise for P contents in the roots and branches. Again, it should be noted that our P contents in the roots were exceptionally high compared with other previous studies (Mun et al., 1977; Lee et al., 1987). In practice, most silvicultural operations are conducted based on size rather than age. Therefore, our current data could be used to determine N and P budgets in fertilization practices or when planning to remove biomass through thinning or harvesting in the region.

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