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Biomass and Nutrients of Planted and Naturally Occurring *Pinus koraiensis* in Korea

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Abstract

Biomass and nutrients (mainly nitrogen (N) and phosphorus (P)) of *Pinus koraiensis* Sieb. et Zucc. were reviewed for plantations and naturally occurring stands in Korea. Slopes of allometric equations to estimate biomass were very similar for different locations while intercepts were different both for plantations and naturally occurring stands. Aboveground biomass ranged from 5.5 Mg ha^{-1} for the 7-year-old plantation to 339.9 Mg ha^{-1} for the 74-year-old plantation, and stem contained approximately more than 50% of aboveground biomass. In naturally occurring stands, seedling aboveground biomass ranged from 2.2 to 6.6. Mg ha^{-1} depending on locations, and the contribution of foliage to aboveground biomass was similar to or even sometimes higher than that of stem. Nitrogen and P contents in overstory aboveground vegetation significantly increased with plantation age. Foliage of *P. koraiensis* in naturally occurring stands contained 56-62% of N and 43-57% of P in total above- plus belowground nutrient contents. Total ecosystem N and P contents of *P. koraiensis* plantations ranged from 4180 kg ha^{-1} to 8990 kg ha^{-1} depending on age, and soils were the largest N and P pools. Nitrogen uptake and retention rapidly increased during the early growing stage due to biomass increase. As the precipitation passes through the canopy its chemistry changed significantly; throughfall and stemflow during the growing season were enriched in all cations and anions.

Key words: allometric regression, biomass, nutrient, *Pinus koraiensis*

Introduction

Pinus koraiensis Sieb. et Zucc. (Korean pine) widely grows in the Amur and maritime provinces of Russia, China, Korea and Japan, and produces high quality wood and nutritive-rich nuts. The species naturally occurs as a mixed forest with different hardwood species in the region (Barnes *et al.* 1992, Zyryanova *et al.* 2005). In Korea, *P. koraiensis* has been extensively planted as pure stands for the past several decades because of high economic value of wood and nuts, and currently occupies approximately 4% of the total forestland area (Korea Forest Service 2005). Recently it is reported that *P. koraiensis* seedlings originating from the surrounding plantations colonized natural deciduous or coniferous forests, and even coniferous plantations (Jin *et al.* 2000, Lee 2002, Son *et al.* 2005). It is also known that colonizing *P. koraiensis* seedlings that survive in the understory show unique morphological and/or physiological characteristics such as high proportion of foliage to total biomass, high specific leaf area, and slow diameter and height growth (Jin *et al.* 2000, Son *et al.* 2005). These seedlings generally have very high densities ranging from 3,000 to 20,000 seedlings per ha and show slow growth with only 10-15cm of diameter at root collar and 2.5-3.3m of height at the age of 20-30 (Ji 2003, Lee 2002, Son *et al.* 2005). Many of the previous studies investigated biomass and nutrients for the species, however, most of them focused on plantations (Son *et al.* 2001, Yi 1998). Only a few studies reported biomass and nutrients of naturally regenerated *P. koraiensis* seedlings (Ji 2003, Lee 2002, Son *et al.* 2005); they used diameter at root collar rather than diameter at breast height to estimate biomass, and found heavy competition with other understory vegetation. Based on the recent findings it is apparent that totally different approaches would be necessary to study biomass and nutrients of *P. koraiensis* for plantations and naturally regenerated seedlings. The primary objective of the current study was to provide an overview of biomass and nutrients for planted and naturally occurring *P. koraiensis* in Korea. We collected and compared data sets from the literature and also included our own unpublished data for the species. Our review focused on nitrogen (N) and phosphorus (P) because these two elements are most commonly limiting production in temperate forest ecosystems.

Allometric equations and biomass estimation

Regression equations

Regression equations to estimate biomass for *P. koraiensis* in the literature are summarized in Table 1. Most of the studies used the destructive harvest method to develop allometric equations, and logarithmic

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regressions of component biomass as a function of diameter at breast height or diameter at root collar were calculated. Regressions were of the form

$\log_{10} Y = a + b \log_{10} X$

where Y is component biomass (kg or g) and X is diameter (cm). The regression equations developed for the species should be carefully compared due to the slight differences in methodology among studies. Like the results of other studies, diameter at breast height for plantations and diameter at root collar for naturally occurring stands explained a large percent of the variation of the component biomass for the species (Table 1). In plantations, coefficients of determination (R^2) ranged from 0.916 to 0.980, and stem or stemwood showed the highest R^2 among tree components. In naturally occurring stands, R^2 was slightly low and stem showed the highest R^2 value compared to other components.

Allometric regressions of stem biomass on diameters at breast height (10-20cm) for plantations (Figure 1a) and regressions to estimate root biomass using diameter at root collar (1-10cm) for naturally occurring stands (Figure 1b) were compared among studies. Interestingly, slopes were very similar while intercepts were quite different for both cases. Also the slopes of branch and foliage for plantations and stem and branch for naturally occurring stands were similar (Figures not shown). These differences might result from the differences in various biotic and abiotic factors among locations. It would suggest that regression equations should be carefully applied to areas outside where they were developed (Gower *et al.* 1987).

Biomass estimation

Studies on biomass using the dimension analysis technique began in late 1960s in Korea, and biomass data for *P. koraiensis* has been published since late 1980s. However, most studies are limited to aboveground biomass for plantations. A summary of biomass for *P. koraiensis* in plantations and naturally occurring stands is presented in Table 2. Aboveground biomass ranged from 5.5 Mg ha^{-1} for the 7-year-old plantation to 339.9 Mg ha^{-1} for the 74-year-old plantation (Kim and Kim 1988, Son *et al.* 2001). Stem contained approximately more than 50% of aboveground biomass. The proportion of tree component (stem, branch and foliage) to total aboveground biomass differed among plantations, however, biomass ranked stem > branch > foliage in general. These patterns were similar to those reported for other coniferous and deciduous trees in Korea (Son 2002, Son *et al.* 2004). Except for the results reported by Son *et al.* (2001), the proportion of foliage to aboveground biomass decreased with plantation age while that of stem to aboveground biomass increased (Table 2). Few studies measured root biomass to estimate total above- plus belowground biomass (Kim and Kim 1988, Lee *et al.* 1987, Noh *et al.* 2005). The proportion of root to total above- plus belowground biomass ranged from 13.4% for the 55-year-old plantation in Gwangju to 27.4% for the 13-year-old plantation in Gapyeong (Lee *et al.* 1987, Noh *et al.* 2005). Aboveground biomass with the similar ages seemed significantly different among plantations. For example, aboveground biomass of the 9-year-old plantation in Chunchon (20.6 Mg/ha) was more than

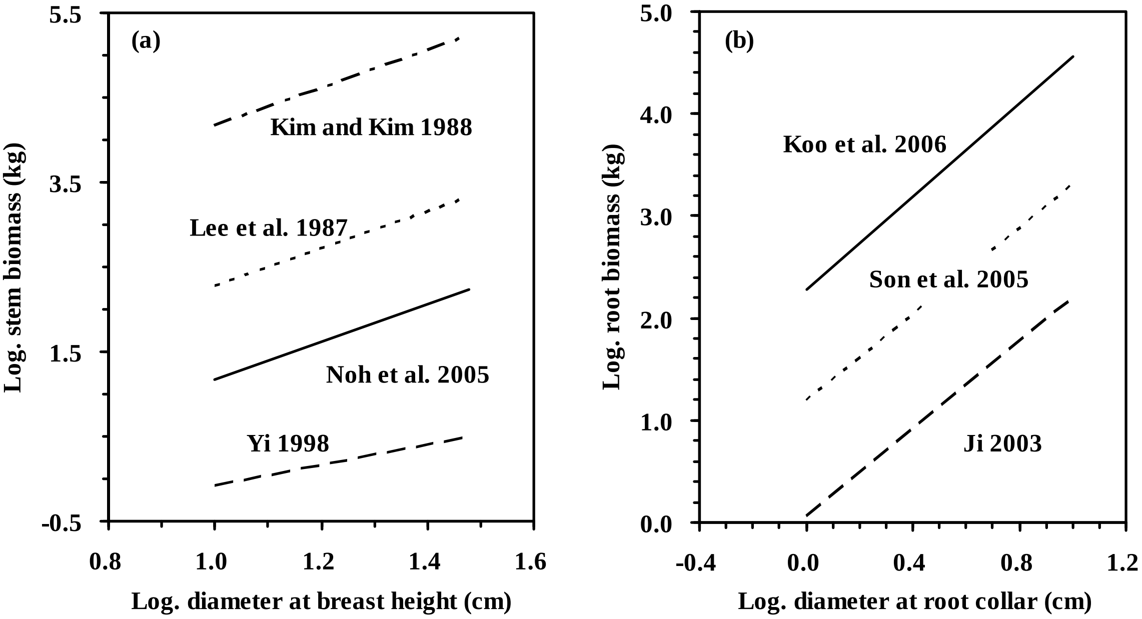

Fig. 1. Relationship between stem biomass and diameter at breast height for *P. koraiensis* plantations (a) and relationship between root biomass and diameter at root collar for naturally occurring stands (b).

Table 1. Regression of component dry mass on diameters for *Pinus koraiensis* in Korea.

Location	Sample size	Age (yr)	Component	a	b	R^2	References
Plantations*							
Yangpyeong	20	21-30	Stemwood	-0.801	2.201	0.962	Son *et al.* 2001
(127^{O}30’E, 37^{O}30’N)			Stembark	-1.329	1.832	0.959	
			Branch	-2.088	2.768	0.933	
			Foliage	-3.693	3.606	0.916	
			Aboveground total	-0.856	2.386	0.974	
Gapyeong			Stemwood	-1.121	2.240	0.943	Noh *et al.* 2005
(127^{O}24’E, 37^{O}54’N)	15	10-59	Stembark	-1.908	2.120	0.937	
			Stem	-1.077	2.246	0.948	
			Branch	-2.186	2.778	0.946	
			Foliage	-2.807	2.967	0.917	
			Aboveground total	-1.110	2.388	0.969	
			Root	-1.505	2.428	0.980	
			Total	-0.961	2.378	0.950	
Chunchon			Stem	-1.289	1.215		Yi 1998
(127^{O}48’E, 37^{O}46’N)	21	9-66	Branch	-1.598	1.165		
			Foliage	-0.954	0.782		
Gwangju			Stem	1.919	2.246	0.968	Kim and Kim 1988
(127^{O}18’E, 37^{O}18’N)		18	Branch	0.977	2.767	0.927	
			Foliage	1.024	2.472	0.922	
Gwangju			Stem	0.083	2.196	0.972	Lee *et al.* 1987
(127^{O}18’E, 37^{O}18’N)			Live branch	0.001	3.379	0.955	
			Dead branch	0.312	0.631	0.932	
			Foliage	0.002	2.897	0.949	
			Aboveground total	0.065	2.472	0.969	
Naturally occuring stands**							
Chunchon	30	4-36	Stemwood	1.363	2.162	0.800	Son *et al.* 2005
(127^{O}5’E, 37^{O}49’N)			Stembark	1.066	1.715	0.917	
			Branch	1.263	2.308	0.816	
			Foliage	1.702	1.644	0.945	
			Aboveground total	1.980	2.004	0.889	
			Root	1.198	2.101	0.875	
			Total	2.052	2.012	0.898	
Gapyeong	40	4-36	Stem	2.499	2.795	0.970	Koo *et al.* 2006
(127^{O}51’E, 37^{O}49’N)			Live branch	1.984	3.556	0.940	
			Dead branch	-0.221	2.441	0.660	
			Foliage	2.693	2.618	0.940	
			Root	2.281	2.273	0.950	
Chunchon	38	4-36	Stem	0.049	2.455	0.962	Ji 2003
			Branch, current	0.044	1.698	0.931	
			1-yr	0.051	1.758	0.928	
			2-yr	0.030	1.947	0.950	
			>2-yr	0.006	2.816	0.976	
			dead	0.001	2.421	0.620	
			Foliage, current	0.167	1.918	0.949	
			1-yr	0.084	1.967	0.962	
			2-yr	0.034	2.186	0.943	
			>2-yr	0.043	2.057	0.887	
			Root	0.066	2.142	0.945	

* $\log Y = a + b \log X$, where Y is the component dry mass (kg) and X is the diameter at breast height (cm).

** $\log Y = a + b \log X$, where Y is the component dry mass (g) and X is the diameter at root collar (cm).

Table 2. Biomass (kg ha-1) of *P. koraiensis* by components in Korea.

Location	Age (yr)	Mean DBH (cm)*	Mean height (m)	Density (no/ha)	Stem	Bark	Branch	Foliage	Aboveground total	Root	Total	References
Plantations												
Yangpyeong	17	10.2		1406	37.8	4.6	9.5	1.7	53.6			Son *et al.* 2001
	26	17.3		1168	93.3	9.6	29.7	7.1	139.7			
	36	21.3		805	130.5	11.9	50.5	16.2	209.1			
	46	32.4		488	163.4	13.4	73.7	29.2	279.7			
	57	34.3		491	167.6	13.6	77.8	32.7	291.7			
	68	38.1		484	181.2	14.0	89.3	40.3	324.8			
	74	44.3		256	178.2	12.9	97.4	51.4	339.9			
Gapyeong	13	9.2		1633	19.5	2.4	6.3	2.4	30.6	11.6	42.2	Noh *et al.* 2005
	30	20.4		633	61.8	6.9	30.4	13.4	112.5	41.2	153.7	
	50	29.2		333	50.3	5.5	27.5	12.6	95.9	34.5	130.4	
Chunchon	9	4.6		4400	10.7		4.4	5.5	20.6			Yi 1998
	22	12.9		1900	61.2		20.1	11.5	92.8			
	34	18.9		844	63.3		22.8	9.6	95.7			
	46	24.6		650	86.2		30.5	11.1	127.8			
	66	30.1		375	90.0		30.3	10.5	130.8			
Gwangju	7	3.4			2.5		1.2	1.8	5.5	1.1	6.6	Kim and Kim 1988
	9	4.9			3.7		2.9	3.0	9.6	2.4	12.0	
	13	9			23.8		9.5	7.2	40.4	9.3	49.7	
	18	13.2			48.8		22.1	11.2	82.2	22.3	104.5	
	22	9.3-20.8			82.7		27.6	12.5	122.9	27.2	150.1	
	55	16.6			106.7		30.0	8.9	145.5	22.5	168.0	
Gwangju	27				42.6		18.3	6.9	67.8	18.4	86.2	Lee *et al.* 1987
Gwangju	28				46.6		19.2	9.5	75.3			Lee and Kim 1997
Naturally occuring stands												
Chunchon	4-36			10750	0.6	0.2	0.6	0.8	2.2	0.4	2.6	Son *et al.* 2005
Gapyeong				4550	1.8		1.7	2.1	5.6	1.2	6.8	Koo *et al.* 2006
Chunchon	4-36	2.8	1.6	4900	2.8		2.2	1.6	6.6	1.0	7.6	Ji 2003
	4-34	1.6	0.9	4300	0.9		0.7	0.9	2.5	0.3	2.8	
	4-34	1.9	1.1	4600	1.3		1.1	1.3	3.7	0.5	4.2	
	4-34	2.6	1.4	3800	2.1		1.7	1.9	5.7	0.7	6.4	
Chunchon				18100	1.2		1.0	1.2	3.5	0.5	4.0	Son unpublished data

* Diameter at beast height for plantations and diameter at root collar for naturally occurring stands.

twice that in Gwangju (9.6 Mg ha^{-1}) although two plantations were about 50 km apart from each other (Kim and Kim 1988, Yi 1998). These data strongly support the importance of site specific allometric equations to estimate biomass.

In naturally occurring stands, seedling aboveground biomass ranged from 2.2 to 6.6.Mg ha^{-1} depending on locations (Table 2). The proportions of seedling component to aboveground biomass were quite different from those of tree component to aboveground biomass in plantations; seedling biomass ranked foliage ≥ stem > branch. Approximately 30-35% of aboveground biomass was contained in foliage, and the contribution of foliage to aboveground biomass was similar to or even sometimes higher than that of stem. Son *et al.* (2005) speculated that naturally occurring understory *P. koraiensis* seedlings allocated more biomass to foliage to exploit the low light flux in a shady conditions. Roots contained about 10-15% of total above- plus belowground biomass in seedlings. These ratios were lower than those in plantations (15-20%).

Aboveground biomass increased with plantation age, and there was a statistically significant positive correlation between aboveground biomass and plantation age (Y = -9.50 + 4.03X, r = 0.83, $p<0.001$) (Figure 2a). In naturally occurring stands, aboveground or total above- plus belowground biomass seemed to change with seedling density (Figure 2b). However, their relationship was not statistically significant (p=0.47 for aboveground biomass and p=0.51 for total biomass). Biomass was very high at low density, decreased at medium density, and slightly increased again at high density. In general, it is known that several seeds of *P. koraiensis* germinate together in a spot and produce relatively high seedling biomass. However, seedling densities decrease due to competition thereafter and small seedlings remain at medium density. It appeared that as competition continues few and large seedlings may produce high seedling biomass (Figure 2b). However, current biomass data had high variation, and the number of case studies were limited, further studies would be needed to conclude the trends of biomass with seedling density for the species. The ratio of root to total biomass may change with plantation age (Kim and Kim 1988, Noh *et al.* 2005); the ratio seemed to be high at the early growing stage and gradually decrease at the mature stage (Figure 3). However, it was difficult to determine age-dependent trend of the ratio because the number of plantations with age sequence was not sufficiently large enough at this point.

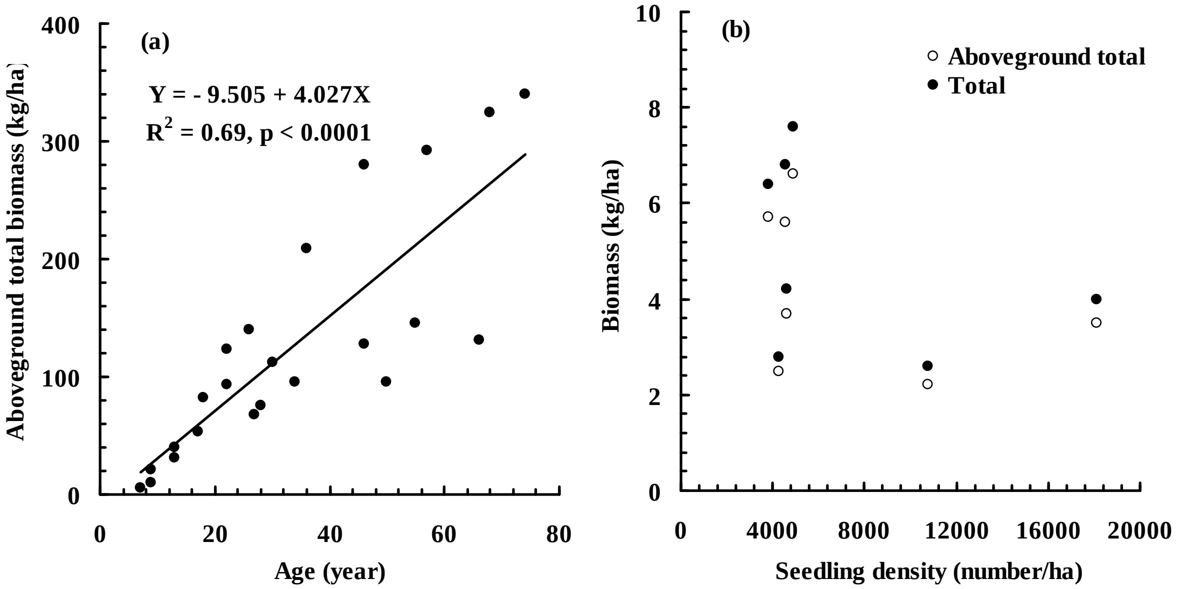

Fig. 2. Relationship between aboveground total biomass and *P. koraiensis* plantation age (Y = -9.505 + 4.027 X, R = 0.83, $p<0.001$) (a) and relationship between biomass and seedling density for naturally occurring stands (b).

Nutrient distribution and cycling

Nutrient contents in vegetation and ecosystems

Nitrogen and P concentrations in *P. koraiensis* and other ecosystem components are presented in Table 3. In general, nutrient concentrations in understory shrubs and herbs were much higher than those in overstory *P. koraiensis* trees or seedlings. Nitrogen and P concentrations varied by tissue in trees or seedlings, and were highest in foliage followed by branch and stem for both plantations and naturally occurring stands. Also N and P concentrations in root were lower than those in foliage, however, they were usually higher than those in stem. In *P. koraiensis*, foliage N concentration ranged from 0.82% to 1.80% for plantations, and varied from 1.39% to 1.78% for naturally occurring stands. There seemed to be no differences in foliage N and P concentrations between plantations and naturally occurring stands.

In plantations, N and P contents within overstory vegetation were highest in foliage followed by stem and branch at the early growing stage, however, they were highest in stem at the mature stage (Table 4). Nitrogen and P contents in overstory aboveground vegetation increased with plantation age, and the relationships were significant ($R^2 = 0.91$ for N and $R^2 = 0.73$ for P) (Figure 4). Biomass of understory herbs was highest at the 1-year-old plantation and continuously decreased with age while that of understory shrubs increased from the 1-year-old plantation, peaked at the 9-year-old plantation and decreased thereafter (Cho and Kim 1989). Nutrient contents in understory vegetation (shrubs plus herbs) were high at the early growing stage, and gradually decreased. Especially nutrients in herbs rapidly decreased with plantation age (Cho and Kim 1989, Yi 1998). On the other hand, N and P contents were highest in foliage followed by branch and stem in naturally occurring stands (Table 4). Foliage of *P. koraiensis* in naturally occurring stands contained 56-62% of N and 43-57% of P in total above- plus belowground nutrient contents.

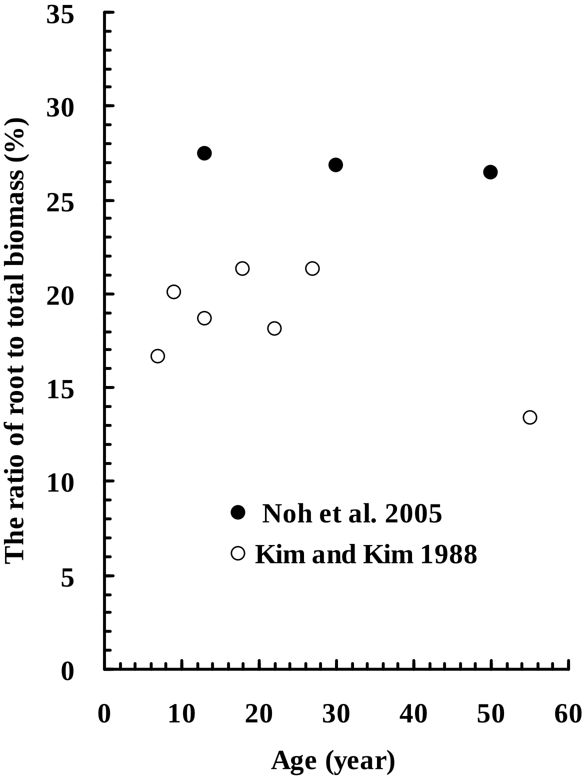

Fig. 3. Changes in the ratio of root to total biomass with plantation age for *P. koraiensis*.

Only one study reported whole ecosystem nutrient contents including belowground and understory components (Cho and Kim 1989). Total ecosystem N contents including soils of *P. koraiensis* plantations ranged from 4180 kg ha^{-1} to 8990 kg ha^{-1} depending on age (Table 4). When we divided a forest ecosystem into three components (overstory plus understory vegetation, forest floor and soil), soils were the largest N and P pools. In an 11-year-old plantation, N contents were distributed: vegetation (4%), forest floor (1%), and soil (95%) (Cho and Kim 1989). However, N and P contents were higher in forest floor than in vegetation in naturally occurring stands due to low biomass accumulation in vegetation (Table 4).

Nutrient uptake, retention and return

Few studies calculated nutrient budgets using the mass balance equation (Cho and Kim 1989, Lee *et al.* 1987). Nitrogen uptake, retention and return (kg ha^{-1} yr^{-1}) was 57.4, 33.8, and 23.8 for a 27-year-old plantation and 52, 37.4, and 14.6 for an 11-year-old plantation, respectively (Cho and Kim 1989, Lee *et al.* 1987). Nitrogen uptake and retention rapidly increased during the early growing stage due to biomass increase (Cho and Kim 1989). The ratio of N return to N uptake increased from 28% for the 11-year-old plantation to 42% for the 27-year-old plantation, and the ratio would increase with age (Son 2002, Son *et al.* 2004). Although Shin and Lee (1985) and Park and Lee (1991) measured seasonal soil inorganic N concentrations for *P. koraiensis* plantations, more detailed studies on on-site N mineralization would be necessary to estimate precise N budgets for the species (Son *et al.* 2004). Kim *et al.* (1997) measured litterfall inputs for a 20-30-year-old *P. koraiensis* plantation in Kwangneung; mean annual litterfall input was 4400 kg ha^{-1} yr^{-1}, and N and P inputs through litterfall were 21.6 and 1.3 kg ha^{-1} yr^{-1}, respectively. The litterfall input value was similar to 4013 kg ha^{-1} for 8 months (March-November) in a 22-year-old plantation (Lee and Park 1987).

Nutrients in hydrologic cycles

Park *et al.* (1999) monitored precipitation chemistry for a 28-year-old *P. koraiensis* plantation; 1410.1mm of water fell during the growing season (May-September), of this 1172.8mm and 18.5mm became throughfall and stemflow, and the remainder was intercepted by the canopy. These values were similar to those reported by Lee *et al.* (1997) in a 25-year-old *P. koraiensis* plantation. Nitrogen input by bulk precipitation was

Table 3. Nitrogen (N) and phosphorus (P) concentrations (%) in vegetation and ecosystem components.

Location	Age (yr)	Element	Stem	Branch	Foliage	Root	Shrub woody	Shrub foliage	Herbs	Forest floor	Soil	References
Plantations												
Chunchon	9-66	N	0.23	0.46	1.80		0.56	2.64	2.44	1.42		Yi 1998
		P	0.05	0.13	0.21		0.18	0.26	0.28	0.13		
Namyangju	1	N	0.48	0.85	1.21							Cho and Kim 1989
	2	N	0.49	0.75	1.56							
	3	N	0.31	0.44	1.53	0.78						
	6	N	0.27	0.44	1.27							
	9	N	0.19	0.4	1.17							
	11	N	0.14	0.37	1.28	0.35						
Gwangju	22	N	0.11	0.26	0.82	0.57	0.44	1.91	2.08	0.32	0.23*	Lee and Park 1987
		P	0.01	0.03	0.11	0.04	0.04	0.11	0.09	<0.01	<0.01	
Gwangju	24	N	0.26	0.29	1.17	0.35	0.54	2.84		0.99	0.13**	Shin and Lee 1985
Naturally occuring stands												
Chunchon**	4-36	N	0.40	0.67	1.43	0.49				1.58	0.26**	Son *et al.* 2005
		P	0.05	0.07	0.13	0.05				0.08	0.03	
Gapyeong		N	0.46	0.68	1.78	0.74				2.00	0.19	Koo *et al.* 2006
		P	0.05	0.05	0.08	0.04				0.07	0.05	
Chunchon****		N	0.33	0.53	1.39	0.33				1.05	0.14	Son, unpublished data
		P	0.04	0.05	0.10	0.04				0.04	0.02	
Chunchon	4-34	N	0.20	0.28	1.48	0.38						Ji 2003
		P	0.04	0.03	0.15	0.17						

* 0-30cm

** 0-20cm

*** *Quercus mongolica* dominated stand

**** Mixed *Quercus* dominated stand

Table 4. Nitrogen (N) and phosphorus (P) contents (kg ha-1) in vegetation and ecosystem components.

Location	Age (yr)	Element	Stem	Branch	Foliage	Root	Shrub woody	Shrub foliage	Shrub belowgroun	Herbs	Herb belowground	Forest floor	Soil	References
Plantations														
Chunchon	9	N	24.50	20.3	98.40		7.67	21.12		14.39		86.12	5487.4*	Yi 1998
		P	5.30	5.7	11.40		2.46	2.08		1.65		7.92	362.7	
	22	N	140.60	92.2	189.50		16.35	7.39		3.41		346.26	6148.9	
		P	30.50	26.0	22.10		5.25	0.72		0.39		33.39	431.4	
	34	N	145.60	104.6	173.50		2.41	3.42		1.22		233.88	7153.2	
		P	31.60	29.5	20.20		0.77	0.33		0.14		22.63	460.9	
	46	N	198.20	140.1	200.50		21.70	14.25		3.17		170.93	5813.4	
		P	37.90	34.3	17.80		7.00	1.40		0.36		16.08	494.1	
	66	N	207.00	139.2	195.10		9.85	11.88		0.48		336.89	8005.2	
		P	45.00	39.3	22.70		3.16	1.17		0.06		32.78	447.5	
Namyangju	1	N	0.10	0.1	0.50	0.10	3.10	23.30	4.3	43.80	4.1	36.50	6480**	Cho and Kim 1989
	2	N	0.80	0.7	2.90	0.90	9.60	20.20	6.1	41.90	4.1	62.60	6450	
	3	N	0.70	0.5	3.60	1.10	9.50	31.60	9.4	33.20	3.6	53.80	4030	
	6	N	13.30	16.0	60.60	11.50	14.20	75.20	17.2	12.20	1.3	51.60	7770	
	9	N	28.80	33.1	101.30	27.80	24.10	85.20	20.2	2.20	0.3	110.00	7260	
	11	N	35.90	43.8	145.40	41.80	22.80	49.40	15.2	1.50	0.2	91.90	8540	
Gwangju	24	N	67.03	64.9	199.82		20.31	2.20						Shin and Lee 1985
Gwangju	22	N	190.75	81.8	128.52	167.54								Lee and Park 1987
		P	5.96	5.9	10.69	8.54								
Naturally occuring stands														
Chunchon	4-36	N	2.28	3.2	12.14	2.01						155.90	5541***	Son *et al.* 2005
		P	0.29	0.4	1.10	0.19						8.70	647.5	
Gapyeong		N	8.84	11.5	36.71	8.61						237.00	4758.5	Koo *et al.* 2006
		P	0.87	0.9	1.67	0.51						7.70	1255.3	
Chunchon		N	4.08	5.3	16.88	1.46						136.50	4321.5	Son, unpublished data
		P	0.54	0.5	1.16	0.16						5.00	824	

* 0-50cm
** 0-10cm
*** 0-30cm

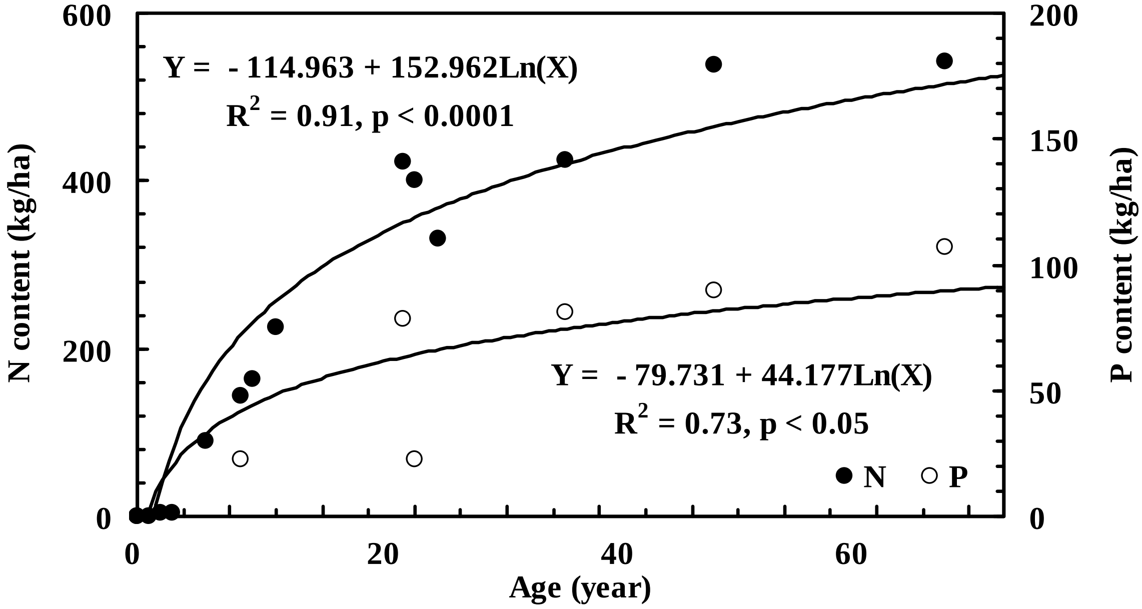

Fig. 4. Relationship between N and P contents in aboveground overstory vegetation and plantation age in *P. koraiensis*.

reported to be 10 kg ha^{-1} yr^{-1} in central Korea (Cho and Kim 1989). As the precipitation passed through the canopy its chemistry changed significantly; throughfall and stemflow during the growing season were enriched in all cations (Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+}) and anions (Cl^-, NO_3^-, and SO_4^{2-}). Especially average monthly input of NH_4^+ was very high (5.6 kg ha^{-1}). Hydrogen ion also increased in throughfall and stemflow due to leaching of dry acid deposition in the canopy (Joo *et al.* 1999, Park *et al.* 1999). Soil solutions were collected by zero-tension lysimeters from a 25-year-old *P. koraiensis* plantation (Ryu and Son 1998), mean soil solution pH of A and B horizons was 4.54 and 4.55, and soil solution NO_3^- concentration was 0.335 meg l^{-1} for O horizon, 0.525 meg l^{-1} for A horizon , and 0.512 meq l^{-1} for B horizon, respectively. These high values seemed to be related to heavy N inputs by acid deposition in the region. And soil solution NO_3^- concentration was positively correlated with K^+ and Mg^{2+} concentrations. These indicated that NO_3^- and cations were leaching from the plantations (Park *et al.* 1999).

Soil microorganisms

Park and Lee (1991) investigated seasonal changes in soil microorganism populations for 8-, 18-, and 28-year-old *P. koraiensis* plantations established following clearcut of *Quercus mongolica*. Populations of nitrifying bacteria, denitrifying bacteria, and cellulose hydrolyzing fungi fluctuated during the growing season, however, there were no differences in population among plantations. Furthermore, populations of these microorganisms did not differ between *P. koraiensis* plantation and *Q. mongolica* stand. They concluded that the influence of clearcut on soil microorganisms was minor although soil carbon and nitrogen concentrations slightly decreased following clearcut.

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