한국생태학회지 27(2): 67～71, 2004 Korean J. Ecol.

Quantitative Comparisons of Soil Carbon and Nutrient Storage in *Larix leptolepis*, *Pinus densiflora* and *Pinus rigitaeda* Plantations

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ABSTRACT : This study was carried out to evaluate soil carbon and nutrient storage of three adjacent coniferous plantations (*Larix leptolepis*, *Pinus densiflora* and *Pinus rigitaeda*) growing on a similar site with a same planting age (42-year old) in the Sambong Exhibition Forests, Hamyang-gun, Gyungsangnam-do. The soil carbon concentration among three plantations was not significantly different in 0～10 cm soil depth, but other two depths (10～20 cm and 20～30 cm) showed higher carbon concentration in *P. densiflora* plantation than the other two plantations. The exchangeable cation concentrations (Ca and Mg) in 0～10 cm depth were significantly lower in *L. leptolepis* plantation than in the other two plantations, while nitrogen and phosphorus concentrations were not significantly different among three plantations except for nitrogen at 10～20 cm depth in *P. rigitaeda* plantation. Soil carbon storage in 0～20 cm depth of three plantations was unaffected by the stand types. Soil nutrient storage was not significantly different at each depth except for nitrogen storage at 10～20 cm depth in *P. rigitaeda* plantation because of the variation of bulk density and coarse fragment. This result demonstrates that soil carbon and nutrient concentrations among the plantations on a similar soil condition can be altered significantly by tree species effects over 40 years after plantation establishment.

Key words : Forest soils, Nutrient storage, Oraganic carbon, Soil property, Stand types

INTRODUCTION

Carbon and nutrient storage in forests has been the focus of researches because of the role of CO_2 in global climate change (McPherson and Simpson 1999, Ballard 2000, Kim and Jeong 2001, Chen and Li 2003). Estimates of changes in forest carbon and nutrient pools have been made at global, national and regional scales (Watson *et al*. 2000, Zinke and Stangenberger 2000, Chen and Li 2003). Many studies reported that forest type may influence forest ecosystem carbon and nutrient storage (Huntington *et al*. 1988, Fernandez *et al*. 1993, Zinke and Stangenberger 2000, Chen and Li 2003). Soil carbon and nutrients can be changed after plantation establishment because tree species have different nutrient requirement and carbon storage mechanisms. In addition, the role and the importance of forests for carbon and nutrient storage are likely to be quite variable with forest types because nutrient converting rates among species were different (Binkley and Giardina 1998).

Although there have been many studies to evaluate the effect of stand types on carbon and nutrient storage (Cromack *et al*. 1999, Chen and Li 2003, Davis *et al*. 2003), major uncertainties remain in relation to the importance and behavior of carbon and nutrient stocks by coniferous plantations in Korea. The objective of this study was to evaluate carbon and nutrient storage of major coniferous types such as *L. leptolepis*, *P. densiflora* and *P. rigitaeda* growing on a similar site with the same planting age.

MATERIALS AND METHODS

The study was conducted in the Sambong Exhibition Forests located in Hamyang-gun, Gyungsangnam-do administered by Seobu National Forest Office, Korea Forest Service. Annual mean precipitation in this area is 1,322 mm/yr and annual mean temperature is 12.8℃. Experimental plots were located in adjacent *P. densiflora*, *L. leptolepis* and *P. rigitaeda* plantations on moderately productive upland sites. These coniferous species were the major planting species for reforestation all over the country during last forty years.

Three plantations were established in 1963 and the study plots were set up on the north-east slope (5～15°) where small pits and mounds were present. The experimental design consisted of three 20 m×10 m plots within each plantation. Dominant understory species in *L. leptolepis* plantation were *Viburnum dilatatum*, *Lindera erythrocarpa*, *Rubus parvifolius*, *Quercus serrata*, *Q. acutissima*, *Q. variabilis*, *Castanea crenata*, *Schizandra chinensis*, *Staphylea bumalda*, *Zanthoxylum schinifolium* and *Elaeagnus umbellata*. Dominant understory species in *P. densiflora* plantation were *Rho-*

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dodendron mucronulatum, *Q. serrata*, *Q. aliena*, *Lindera. glauca*, *L. obtusioloba*, *Smilax china* and *Juglans mandshurica*. Dominant understory species in *P. rigitaeda* plantation were *Styrax japonica*, *Stephanandra incisa*, *Z. schinifolium*, *Cornus controversa*, *Q. aliena*, *Q. serrata*. *Symplocos chinensis* for. *pilosa*, *J. mandshurica* and *Rhus sylvetris*.

Mean stand densities (trees/ha) of each plantation were 216 for *P. densiflora*, 350 for *L. leptolepis* and 566 for *P. rigitaeda* plantations (Table 1). Mean DBH (cm) was greatest in *P. densiflora* (32.4), followed by *L. leptolepis* (30.5) and *P. rigitaeda* plantations (27.9). Stand basal area (m^2/ha) was 35.6 in *P. rigitaeda*, 26.4 in *L leptolepis* and 18.3 in *P. densiflora* plantations. We think that the difference of DBH and stand basal area among three plantations was due to common forest management practices such as thinning. Aboveground carbon storage in *P. rigitaeda* having the greatest basal area was higher than the other two plantations (Table 1). Other study reported that carbon storage in a 31-year old *P. rigida* plantation in Gwangnung was closely related to basal area of plantations (Kim and Jeong 2001).

Soil samples to measure soil carbon and nutrient concentration were collected in October 2002 from three randomly selected points in each plot. At each point, a soil pit of 50 cm×50 cm was collected to soil samples in three depths (0～10 cm, 10～20 cm and 20～30 cm). Soil samples to determine bulk density were collected at each soil depth by using 100 cc stainless cans. Bulk density was determined after drying at 105℃ for 24 hours. Five bulk soil samples for each depth were collected and the collected soil samples were air-dried and sieved by through a 2 mm sieve prior to soil carbon and nutrient analysis.

Loss on ignition at 375℃ for 16 hours was determined for mineral soil samples and converted to percent carbon (Soon and Abboud 1991). All soil nutrients (total N, available P, K, Ca and Mg) were analyzed by the standard method of National Institute of Agricultural Science and Technology (2000). We calculated a mass per unit area of carbon and nutrients for mineral soil from bulk density, nutrient concentration, soil thickness data and volume of coarse fragment by the equation given by Cromack *et al*. (1999).

The data obtained among three plantations were compared in terms of carbon and nutrient concentrations and storage in mineral soils using analysis of variance and Tukey test for mean separation analysis (SAS Institute Inc. 1989).

RESULTS AND DISCUSSION

Soil bulk density was significantly different among three plantations (p<0.05). The bulk density in the surface depth (0～10cm) was lower in *P. densiflora* plantation than in other two plantations (Table 2) because soil bulk density could be affected by soil organic carbon concentration (Cromack *et al*. 1999). Low bulk density in *P. densiflora* plantation could be due to high organic carbon concentration compared with other two plantations (Table 3) by increased sources of organic matter such as fine roots and litterfall under dense understory vegetation. Volumetric coarse fragment content (>2 mm) of each depth except for the surface depth was not significantly different (p>0.05) among three plantations indicating a similar site condition (Table 2).

Soil carbon concentration decreased with soil depth (Table 3) and it was higher in the surface depth (0～10 cm) than in the subsurface depths (10～30 cm). High carbon concentration of the surface depth could be due to the inputs of organic matter decomposed from litterfall and fine roots (Jeong *et al*. 1998). Carbon concentration of the surface depth (0～10 cm) ranged from 7.26% to 8.51% among three plantations. Carbon concentration was 2.8～3.6 fold higher in these plantations than in other Korean forest soils. Jeong *et al*. (1998) reported that carbon concentration in A horizon of the Korean forest soils was less than 2.6%.

The carbon concentration among three plantations was not significantly different in 0～10 cm depth (p>0.05), but that in other

Table 1. General characteristics of three coniferous plantations in the study sites

Plantation	Location	Elevation (m)	Stand density (trees/ha)	DBH (cm)	Height (m)	Basal area (m^2/ha)	Aboveground biomass carbon (MgC/ha)
L. leptolepis	35°27 ′440 ″ N 127°38 ′492 ″ E	674	350	30.5/ 26.6～35.3	22.7/ 19.8～24.8	26.36/ 17.2～34.3	46.3/ 29.6～61.1
P. densiflora	35°27 ′474 ″ N 128°38 ′ 446 ″ E	684	216	32.4/ 22.0～39.4	14.6/ 12.5～16	18.28/ 17.2～19.2	30.7/ 24.8～35.9
P. rigitaeda	35°27 ′445 ″ N 128°38 ′512 ″ E	678	566	27.9/ 26.5～28.6	20.2/ 18.5～21.9	35.61/ 29.8～42.6	77.2/ 64.6～92.3

note : mean (n=3)/min～max.

Table 2. Soil bulk density and volumetric coarse fragment of three coniferous plantations (standard errors in parenthesis)

Soil depth (cm)	Plantation	Bulk density (Mg/m^3)	Volumetric coarse fragment (>2mm) (%)
0～10	*L. leptolepis*	0.67(0.01)a	20.5(0.50)ab
	P. densiflora	0.56(0.02)b	17.9(0.6)b
	P. rigitaeda	0.69(0.03)a	22.1(1.3)a
10～20	*L. leptolepis*	0.71(0.02)a	21.6(0.8)a
	P. densiflora	0.68(0.05)a	23.8(1.4)a
	P. rigitaeda	0.73(0.01)a	23.0(0.7)a
20～30	*L. leptolepis*	-	19.6(0.9)a
	P. densiflora	-	22.2(1.4)a
	P. rigitaeda	-	23.0(0.9)a

note: - not measured, same letters within tree species by each depth indicate no significance at p = 0.05.

depths showed a significant difference (p<0.05). The carbon concentration in the subsurface depth was significantly higher in *P. densiflora* than in the other two plantations (p<0.05). High understory vegetation cover (above 90% cover rates) by *Rhododendron mucronulatum* in *P. densiflora* plantation compared with other two plantations could increase sources of organic carbon by the litter inputs such as dead fine roots. Similarly, Chen and Li (2003) reported that shrub could store more carbon at the deep soil horizon because shrub may allocate more biomass to root, especially fine roots.

Although we have no data on soil conditions prior to plantation establishment, soil nutrient concentration after plantation development showed significant difference (p<0.05) among stand types. The soil exchangeable cations (Ca and Mg) in the surface depth (0～10 cm) were significantly lower in *L. leptolepis* than in other two plantaions (p<0.05), but nitrogen and phosphorus concentrations were not significantly different among three plantations except for 10～20 cm depth of *P. rigitaeda* plantation (p>0.05). Fyles and C té (1994) reported that difference of nitogen and phosphorus between the species was less pronounced in the mineral soil compared with the forest floor. However, the difference of exchangeable cation concentrations in the mineral soil may be arisen from inherent mineralogical character, tree root distribution, nutrient requirements, nutrient uptake and nutrient allocation throughout plantation development (Binkley and Giardina 1998). For example, rapid uptake and accumulation of nutrients in tree biomass of *L. leptolepis* may be served as the main mechanism responsible for this low exchangeable cation concentration. Many studies reported that larch showed high nutrient uptake characteristics compared with pine species suggesting nutrient-decreased conditions in mineral soils (Son and Gower 1992, Kim 1999). Also, this may be due to partially the result of greater leaching losses under larch associated with production of NO_3^- by microbial transformations compared with pine. Son and Lee (1997) reported that percent nitrification was 45% for pine and 90% for larch species under a similar environment and soil type. In contrast, Bergkvist and Folkeson (1995) found that Norway spruce (*Picea abies*) stands in Sweden accumulated more base cations in both biomass and soil exchangeable pools than did adjacent stands of either birch (*Betula pendula*) or beech (*Fagus*

Table 3. Soil carbon and nutrient concentrations at each depth of three coniferous plantations (standard errors in parenthesis)

Soil depth (cm)	Plantation	C (%)	N (%)	P (mg/kg)	K	Ca	Mg
						($cmol_c$/kg)	
0～10	*L. leptolepis*	7.39(0.56)a	0.46(0.08)a	11.2 (2.52)a	0.39(0.04)ab	0.92(0.14)b	0.40(0.10)b
	P. densiflora	8.51(0.36)a	0.45(0.03)a	6.64(0.96)a	0.53(0.04)a	1.71(0.21)a	0.74(0.07)a
	P. rigitaeda	7.26(0.19)a	0.38(0.03)a	10.42(1.2)a	0.30(0.04)b	1.67(0.12)a	0.81(0.04)a
10～20	*L. leptolepis*	5.31(0.30)b	0.34(0.02)a	4.98(1.5)a	0.39(0.16)a	0.53(0.19)a	0.33(0.07)a
	P. densiflora	6.66(0.25)a	0.34(0.01)a	2.15(0.69)a	0.31(0.02)a	0.50(0.09)a	0.39(0.06)a
	P. rigitaeda	5.57(0.27)b	0.22(0.01)b	3.73(0.89)a	0.16(0.01)a	0.69(0.27)a	0.34(0.06)a
20～30	*L. leptolepis*	3.85(0.22)b	0.19(0.02)a	0.68(0.04)a	0.20(0.03)a	0.22(0.003)a	0.27(0.09)a
	P. densiflora	5.68(0.26)a	0.27(0.02)a	0.98(0.54)a	0.24(0.03)a	0.39(0.08)a	0.30(0.03)a
	P. rigitaeda	4.19(0.16)b	0.22(0.07)a	4.19(2.13)a	0.17(0.03)a	0.64(0.19)a	0.32(0.07)a

Same letters within tree species by each depth indicate no significance at p = 0.05.

silvatica) because of faster rates of mineral weathering in Norway spruce (*Picea abies*) stands.

Carbon storage of three plantations was not significantly different (p>0.05) among the depths except for 20～30 cm depth (Table 4). Soil carbon storage under three plantation has a similar storage trend at each depth. Although three plantations may have different mechanisms in carbon cycle by different litterfall inputs and stand characteristics, the consequences of soil carbon storage among three plantations could be minimal during plantation development.

Soil organic carbon storage (MgC/ha) among three plantations was 102.6 for *P. densiflora*, 94.1 for *P. rigitaeda* and 91.2 for *L. leptolepis* (Table 4). The soil organic carbon storage of three plantations was higher than 67 MgC/ha of Korean forest soils (Jeong *et al*. 1998). Alban and Perala (1992) reported that soil carbon storage was not affected by plantation development and harvesting in aspen ecosytem in Great Lake States, USA.

Soil nutrient storage was not significantly different (p>0.05) at each depth among three plantations except for nitrogen storage at 10~20 cm depth in *P. rigitaeda* plantation (Table 4). Although Ca and Mg concentrations among three plantations showed the significant difference (p<0.05) on the surface depth, the total storage of these cations did not differ by species. This may be due to considerable variation in three variables used to calculate soil nutrient pool: nutrient concentration, bulk density and coarse fragment (Fernandez *et al*. 1993).

The most abundant nutrient in three plantations was N, followed by Ca > K > Mg > P , but in *L. leptolepis* plantation the potassium was slightly higher than calcium (Table 4). Although nutrient storage was not significantly different among three plantations, soil N and K contents were higher in *L. leptolepis* plantation than in *P. densiflora* and *P. rigitaeda* plantations, while Ca and Mg was lower in *L. leptolepis* plantation.

In summary, the carbon concentration in the subsurface depth (10～30 cm) showed higher in *P. densiflora* plantation than the other two plantations. The exchangeable cation concentrations (Ca and Mg) in the surface depth (0～10 cm) were significantly lower in *L. leptolepis* than in the other two plantations (p<0.05). However, soil carbon and nutrient storage was relatively unaffected by stand types. The result indicates that soil carbon and nutrient concentrations on a similar soil condition can be altered significantly over 40 years of plantation establishment.

ACKNOWLEDGEMENTS

The authors are grateful to two anonymous referees for their comments on the manuscripts.

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Table 4. Soil carbon and nutrient storage at each depth of three coniferous plantations (standard errors in parenthesis)

Soil depth (cm)	Plantation	C (MgC/ha)	N	P	K	Ca	Mg
			(kg/ha)				
0～10	*L. leptolepis*	39.3(3.15)a	2,575(599)a	6.2(1.50)a	84(9)a	104(23)a	27(8)a
	P. densiflora	38.6(1.51)a	2,028(29)a	3.1(0.60)a	94(6)a	158(26)a	41(5)a
	P. rigitaeda	39.1(1.73)a	1,988(144)a	5.4(0.59)a	62(9)a	174(10)a	51(2)a
10～20	*L. leptolepis*	29.8(2.38)a	1,993(123)a	2.9(0.86)a	89(37)a	61(21)a	23(5)a
	P. densiflora	34.3(1.73)a	1,772(133)a	1.2(0.42)a	62(4)a	53(12)a	25(5)a
	P. rigitaeda	31.4(1.49)a	1,231(79)b	2.0(0.41)a	33(1)a	74(28)a	23(5)a
20～30	*L. leptolepis*	22.1(1.86)b	1,107(129)a	0.4(0.03)a	47(5)a	26(1)a	19(6)a
	P. densiflora	29.9(1.90)a	1,417(126)a	0.5(0.31)a	49(7)a	41(10)a	19(1)a
	P. rigitaeda	23.6(1.00)b	1,239(480)a	2.4(1.28)a	36(7)a	72(24)a	22(5)a
Total	*L. leptolepis*	91.2(7.3)a	5,675(842)a	9.5(0.81)a	218(34)a	192(17)a	70(8)a
	P. densiflora	102.6(5.1)a	5,217(258)a	4.8(1.16)a	204(17)a	252(40)a	85(10)a
	P. rigitaeda	94.1(4.2)a	4,458(695)a	9.8(1.60)a	131(17)a	321(46)a	96(10)a

Same letters within tree species by each depth indicate no significance at p = 0.05.

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(*Received December 11, 2003; Accepted March 17, 2004*)