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Carbon Storage in Aboveground, Root, and Soil of *Pinus densiflora* Stand in Six Different Sites, Korea

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ABSTRACT

Due to the increase of carbon dioxide in the atmosphere and global warming, the importance of forest ecosystems, as a place of carbon accumulation and emission, has received a great amount of recognition lately. This study was performed to help understand and provide the current status of carbon cycle in the *pinus densiflora* stand, Korea. The samples were collected from average 35-years-old *Pinus densiflora* stands in Gongju, Youngdong, Chungsan, Muju, Mupung, and Jangsu regions. Total thirty aboveground sample trees were cut, and ten roots were sampled, and soil samples were collected. Average carbon concentrations in foliage, branch, stem bark, stem wood, and root were 55.7%, 56.0%, 56.0%, 57.3%, and 56.5%, respectively. Carbon content was estimated by the model $Wt=aD^b$ where Wt is oven-dry weight in kg and D is DBH in cm. Total carbon content (aboveground and root) was 42.39tonC/ha in the *Pinus densiflora* stand. The proportion of each tree component to total carbon content was high in order of stemwood, root, branch, stembark, and foliage. Total net primary production (aboveground and root) was estimated at 6.51tonC/ha/yr in *Pinus densiflora* stand. The proportion of each tree component to total net primary carbon content was high in order of stemwood, root, branch, foliage and stembark. Soil carbon contents in the study sites was 43.51tonC/ha at 0-50cm soil depth.

Key Words : *Carbon accumulation, Carbon content, Net primary production.*

I. INTRODUCTION

As the earth's average air temperature reached an all-time high recently, many scientists expressed concern about the potential for significant global warming as a result of increased carbon dioxide

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(CO_2) and other greenhouse gases (CFCs, CH_4, and N_2O) within the coming century (Schlesinger, 1991; Hansen, 1992). Even small changes in temperature can have dramatic impacts on the earth's complex atmosphere, ocean, land, and life systems (Hair and Sampson, 1992). Increasing population and economic activity will cause in increases the concentration of CO_2 in the atmosphere and may accelerate changes in global climate which may have important consequences for the earth's ecology.

There have been a number of studies to solve the issues of increased carbon dioxide and global warming from different perspectives. For instance, Tans et al. (1990) and Post et al. (1990) demonstrated carbon emission and accumulation over the whole planet. Dixon et al. (1994) studied medium and storage location of carbon emission. Also, a solution to prevent the increase of carbon dioxide in the atmosphere was sought by several researchers (Kurz et al., 1992; Sedjo, 1989; Vitousek, 1991; Dixon et al., 1994).

Forests have received considerable attention because they are a major sink for the carbon cycle. Forest ecosystems account for 90% of aboveground carbon accumulation of terrestrial ecosystems and 40% of belowground carbon accumulation (Waring and Schlesinger, 1985). Furthermore, the carbon cycle between the land and atmosphere is greater than that between the oceans and atmosphere (Winjum et al., 1992). As such, forest ecosystems are supposed to play a very useful role in preventing an increase of carbon dioxide in the atmosphere.

In Korea, 65% of the nation is forest ecosystems. Thus, the importance of forest ecosystems as a main storage location of carbon should be considered. However, the number of studies on carbon accumulation of forest ecosystems in Korea has been limited and their importance has been less emphasized. This study was performed to investigate carbon accumulation in *Pinus densiflora* stand in Gongju, Youngdong, Chungsan, Muju, Mupung, and Jangsu, Korea.

II. MATERIALS AND METHODS

1. Study area

This study was carried out in *Pinus densiflora* stands located in Gongju of Chungchungnam-Do Province, Youngdong and Chungsan of Chungchungbuk-Do province, and Muju, Mupung, and Jangsu of Chollabuk-Do Province, Korea (Figure 1). Historical meteorological data in these areas showed that the annual average temperature is 12.3℃ in Chungchungnam-Do Province, 10.7℃ in Chungchungbuk-Do Province, and 10.4℃ in Chollabuk-Do Province, and the annual average amount of precipitation is 1,354 mm in Chungchungnam-Do Province, 1,260 mm in Chungchungbuk-Do Province, and 1,422 mm in Chollabuk-Do Province with intensive rainfall from June to August.

The average age of the *Pinus densiflora* stands

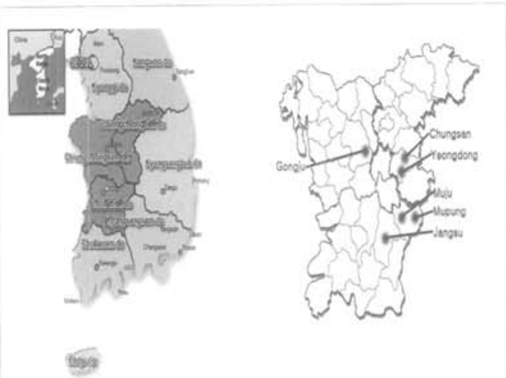

Figure 1. Location of study areas.

Table 1. Aboveground sample descriptions of *Pinus densiflora* stands in Gongju, Yeoungdong, Chungsan, Muju, Mupung, and Jangsu areas.

	DBH of sample tree (cm)	Age of sample tree (yr)	Height of sample tree (m)		DBH of sample tree (cm)	Age of sample tree (yr)	Height of sample tree (m)
	9.7	20	8.7		10.7	35	12.0
	13.0	22	9.8		13.6	35	10.9
Gongju	16.3	22	10.6	Chungsan	15.9	30	11.0
	17.8	24	10.6		18.5	36	12.7
	20.8	24	10.0		22.2	42	11.0
	12.0	39	11.9		12.0	30	9.5
	17.0	36	11.2		17.5	54	14.2
Muju	22.0	37	12.9	Mupung	21.0	43	12.5
	27.5	39	16.7		24.0	47	17.2
	28.0	40	17.5		31.5	47	14.9
	7.0	24	4.9		11.0	29	10.1
	11.5	33	9.0		14.0	36	14.7
Yeoungdong	14.8	36	7.5	Jangsu	18.0	32	13.1
	17.5	38	7.6		24.0	37	15.2
	22.0	41	10.6		27.0	38	15.6
		Mean			17.9	34.9	11.8

was 35.0 years old. The diameter at breast height of the *Pinus densiflora* stands ranges from 7.0 cm to 31.5 cm. The height of the sample trees ranges from 4.9 m to 17.5 m. The number of trees per ha was 408 for the *Pinus densiflora* stand (Table 1, 2).

Table 2. DBH class and number of trees per hectare of *Pinus densiflora* stand in Gongju, Youngdong, Chungsan, Muju, Mupung, and Jangsu areas.

DBH (cm)	No. of tree/ha	DBH (cm)	No. of tree/ha
6	100.0	22	66.7
8	95.8	24	75.0
10	100.0	26	12.5
12	170.8	28	29.2
14	50.0	30	4.2
16	120.8	32	0.0
18	116.7	34	4.2
20	87.5		
	Total		408

2. Data collection and analysis

Sampling was conducted from soil, root and aboveground in August and September, 2007. For the diameter measurement, total 24 quadrats of 20 m×20 m were installed in the total six study plots. To investigate aboveground carbon accumulation, five sample trees were selected from each plot. A total of thirteen trees were cut at a height of 20 cm aboveground; stemwood was cut every 2 m; and the weight of the tree was measured by a scale.

A sample disc of width around 10 cm was cut from every 2 m of each tree and those wet weight was measured by a scale and then it was delivered to the laboratory. All branches on the stemwood were cut and the wet weight were measured. In addition, part of the branches were selected and those wet weight were measured and delivered to the laboratory to measure the dry weight. A sample of leaf was delivered to laboratory and was dried at 75～80℃ in a dry oven.

Two root samples in each study plots (total ten root samples) were collected using an excavation method and their wet weight were measured. Part of the root samples were delivered to the laboratory and dried in dry oven to measure dry weight. The net primary production of root was calculated by multiplying the weight of root by the ratio of the dry weight of branch and stem on net primary production of branch and stem (Park and Moon, 1994). Carbon concentration of each part of the aboveground measurements was analyzed through the loss on ignition method.

Net primary production of stemwood was achieved by calculating the last five years of volume growth using Smalian formula (Kim, 1992).

(Smalian formula)

$V=(g1+g2)/2\times L$

V : volume of log

g1 : cross-section area of log

g2 : cross-section area at the end of log

L : length of log

Net primary production of stemwood was again divided into five and the annual average volume growth was calculated. Dry weight was calculated by using ratio of the annual average volume growth to total stemwood content. The net primary production of stembark was calculated by applying the annual growth rate of stemwood. Leaf was used from material already selected and branch was estimated by adding the current twig sum to the value achieved by Whittaker's formula (Whittaker and Marks, 1975); five branch trunks were selected from a single tree and branch age was measured.

(Whittaker formula)

$W=Bw/A$

W : annual growth of live branch

w : dry weight (kg) of branch

A : branch age

B : slope constant from regression of branch age and dry weight of branch

The regression model, logWt=A+BlogD (Wt=dry weight (kg), D=DBH (cm), A=slope constant, B= slope constant), was used to derive aboveground carbon content and the net primary carbon production equation. The diameter of breast height of the tree screened by diameter measurement was substituted into the derived formula to estimate dry weight in each diameter of breast height. Thus, aboveground carbon content and net primary carbon production of the study stand were estimated by summing up those of each diameter of breast height.

To evaluate carbon content in soil, a total of eighteen sites were selected and soil samples were taken at four different soil depths (0～10 cm, 10～20 cm, 20～30 cm, 30～50 cm) of each site. Soil samples were delivered to the laboratory and dried in shade condition. Dried soils were sieved to pass through a 2 mm sieve. Soil carbon concentration was estimated by 0.58 times of soil organic matter. Bulk density was also estimated by weight of oven dry soil / volume of soil. Carbon accumulation was calculated by the following formula (Rural Development Administration, 2000).

(Soil carbon content formula)

$CSi=T\times BD\times C\times(1-CF)\times 10$

CSi=carbon content in soil (Mg/ha)

T=soil depth (m)

BD=soil bulk density (mg/m^3),

Table 3. Soil characteristics of study sites in Gongju, Yeoungdong, Chungsan, Muju, Mupung, and Jangsu areas.

Study sites	Texture	OM(%)	Total N (%)	Ava-P (ppm)	Exc-K (me/100g)	Exc-Ca (me/100g)	pH(1 : 5)
Gongju	CL	4.64	0.23	2.25	0.43	0.47	4.51
Yeoungdong	CL	6.07	0.24	0.90	0.53	0.76	4.24
Chungsan	SCL	4.67	0.22	1.93	0.37	2.60	4.50
Muju	SiCL	6.67	0.33	0.09	0.64	4.30	4.96
Mupung	CL	9.38	0.35	1.00	0.39	2.00	4.35
Jangsu	SiCL	3.75	0.19	0.55	0.35	0.72	4.61

C=organic carbon concentration (g/kg)
CF=coarse fraction (%)

In order to investigate soil characteristics of the study sites, soil samples were collected at 0-10cm soil depth. One gram soil subsamples were analyzed for organic matter concentration using the Walkely-Black wet oxidation method (Bickehaupt and White, 1982); pH was analyzed by the ratio of 1 : 5; total nitrogen concentration was analyzed by the macro-Kjeldahl method; exchangeable K and Ca was analyzed by Inductively Coupled Plasma Optical Emission Spectrometers. Table 3 shows soil characteristic of the six study sites.

III. RESULTS AND DISCUSSION

1. Carbon concentration in stemwood, stembark, foliage, branch, and root

Table 4 shows the results of carbon concentration analysis of each tree component : foliage, branch, stembark, stemwood, and root of the *Pinus densiflora* stand. The carbon concentrations in foliage, branch, stembark, stemwood, and root were 55.7%; 56.0%; 56.0%; 57.3%; and 56.5%, respectively. Generally, the carbon concentration of trees was found to be 50% of dry weight (Satoo and Madgwick, 1982; Song and Lee, 1996), however, this study showed that the carbon concentration in *Pinus densiflora* was slightly higher than expected. The highest carbon concentration was recorded in the part of stemwood of *Pinus densiflora* stand.

2. Carbon contents in aboveground and root

In the case of aboveground, R^2 values of regression were all around 0.899 showing a relatively high correlation in the study stand (Table 5). The values of stemwood, which accounts for 69.7% of the aboveground totals,

Table 4. Carbon concentrations (%) in foliage, branch, stembark, stemwood and root of *Pinus densiflora* stand in Gongju, Yeoungdong, Chungsan, Muju, Mupung, and Jangsu areas.

Tree component	Gongju (%)	Yeongdong (%)	Chungsan (%)	Muju (%)	Mupung (%)	Jangsu (%)
Foliage	55.9±0.36*	55.8±0.85	55.7±1.04	55.2±0.72	55.6±0.47	55.8±0.91
Branch	55.7±0.14	55.4±0.28	57.0±0.49	56.1±0.21	55.9±0.14	55.7±0.42
Stembark	56.3±0.00	55.8±0.07	55.8±0.71	56.2±0.71	55.6±0.49	56.6±0.07
Stemwood	56.9±0.21	57.0±0.14	57.6±0.07	57.6±0.35	57.2±0.28	57.6±0.00
Root	56.7±0.14	56.3±0.35	56.1±0.28	56.1±0.14	57.0±0.28	56.9±0.21

* Standard deviation.

Table 5. Organic carbon estimation equation of individual tree biomass of *Pinus densiflora* stand. Equation form : logWt=A+BlogD, where Wt is weight in g, D is DBH in cm.

Tree Component	A	B	R^2	F Value	Pr > F
Stemwood	1.683	2.199	0.837	143.77	<.0001
Stembark	0.752	2.181	0.709	68.07	<.0001
Branch	0.724	2.485	0.667	55.98	<.0001
Leaf	1.609	1.351	0.363	15.98	0.0004
Root	0.941	2.430	0.714	24.98	0.0005
Aboveground total	1.857	2.206	0.899	248.58	<.0001

were 0.837. Park and Kim (1989) and Park and Lee(1990) reported that the R^2 values of regression in aboveground and root of *Pinus densiflora* stand was all over 0.800. However, as shown in Table 5, there was relatively low correlation in foliage, branch, root and stembark. Especially, there was very low correlation in foliage because of large difference in leaf biomass among study sites.

The total aboveground carbon content in the *Pinus densiflora* stand was 33.92 tonC/ha (Table 6). A number of other studies abroad reported various carbon content of the pine tree. For instance, the total aboveground carbon accumulation of 16 year-old *Pinus densiflora* stand from Japan was 24.6 tonC/ha (Ovington, 1965); that of 15 year-old *Pinus densiflora* stand from Japan was 31.98 tonC/ha (Satoo, 1966); that of 46 year-old *Pinus nigra* stand from Japan was 121.1 tonC/ha (Ovington, 1956); that of 41 year-old *Pinus strobus* stand was 102.1tonC/ha (Ovington, 1965). The total carbon accumulation (aboveground and root) of 30-40 year-old *Pinus densiflora* stand of Korea was 28.1 tonC/ha in stand of Ankang form, 108.9 tonC/ha in stand of flatland form, 131.6 tonC/ha in stand of highland form, and 203.2 tonC/ha in stand of Keumkang form.

The carbon content of other trees whose stand ages were similar to those of this study was reported by Song and Lee (1996). The aboveground carbon accumulation of a 39 year-old *Quercus mongolica* stand in the Choongju area of Korea was at 48.85 tonC/ha and this is a higher value than that of this study.

Table 6. Organic carbon content at stand of *Pinus densiflora*.

Tree Component	(tonC/ha)	Total (%)	Aboveground (%)
Stemwood	23.63	55.7	69.7
Stembark	2.63	6.2	7.7
Branch	5.97	14.1	17.6
Foliage	1.69	4.0	5.0
Root	8.47	20.0	
Aboveground total	33.92	80.0	100.0
Total	42.39	100.0	

The primary part of total carbon accumulation (aboveground and root) in this study was stemwood. The value of *Pinus densiflora* stand was 23.63 tonC/ha (55.7%). These findings were slightly higher or lower than Park and Lee (1990) (*Pinus densiflora* stand : 37.1% in Ankang form, 56.6% in flatland form, 58.4% in highland form, 61.0% in Keumkang form) and also Song and Lee (1996) (*Quercus mongolica* stand : 58.0% and *Quercus variabilis* stand : 61.0%). As table 6 shows, the value of stembark, branch, foliage, and root was 2.63 tonC/ha (6.2%), 5.97 tonC/ha (14.1%), 1.69 tonC/ha (4.0%), and 8.47 tonC/ha

Table 7. Organic carbon estimation equation of individual tree NPP in *Pinus densiflora* stand. Equation form : logWt=A+BlogD, where Wt is weight in g, D is DBH in cm.

Tree Component	A	B	R^2	F Value	Pr > F
Stemwood	0.722	2.263	0.779	98.48	<.0001
Stembark	-0.208	2.245	0.650	51.97	<.0001
Branch	0.436	2.109	0.716	70.62	<.0001
Leaf	1.497	1.233	0.304	12.17	0.0016
Root	-0.211	2.647	0.769	33.22	0.0002
Aboveground total	1.287	2.037	0.887	220.23	<.0001

(20.0%), respectively.

3. Net primary carbon production in root and aboveground

In the case of aboveground, R^2 values of regression were all around 0.887 showing a relatively high correlation in the selected stand. The values of stemwood, which accounts for 58.2% of the aboveground totals, was 0.779. As shown in Table 7, there was low correlation in foliage, branch, root, and stembark. Especially, there was very low correlation in foliage because of large difference in leaf biomass among study sites.

Table 8 shows the results of net primary carbon accumulation (aboveground and root carbon) in the *Pinus densiflora* stand. Total net primary carbon production (aboveground and root) was 6.51 tonC/ha/yr. Satoo (1966) reported that net primary production in aboveground of *Pinus densiflora* stand in Japan was ranged from 6.1 to 7.5 tonC/ha/yr. Net primary carbon production (aboveground and root) of *Pinus densiflora* stand in four study region of Korea was ranged from 1.86 to 8.25 tonC/ha/yr (Park and Lee, 1990). The carbon content of hardwood forest in Korea's forest ecosystems shows a range of 1.5～9 tonC/ha/yr with the highest frequency in the range 1.5～3 tonC/ha/yr (Kim and Jung, 1985). The results of this study show that the carbon content is in the range of those values.

Table 8. NPP of organic carbon in *Pinus densiflora* stand.

Tree Component	NPP (ton)	Total (%)	Aboveground total (%)
Stemwood	3.12	48.0	58.2
Stembark	0.35	5.3	6.5
Branch	0.96	14.7	17.8
Leaf	0.94	14.5	17.6
Root	1.14	17.5	
Aboveground Total	5.37	82.5	100.0
Total	6.51	100.0	

The primary part of net primary carbon production (aboveground and root) in this study was stemwood (48.0%). However, Park and Lee (1990) reported that the primary part of net primary production of *Pinus densiflora* stand in four study regions of Korea was in foliage. As shown in table 8, the net primary productions of stembark, branch, foliage, and root were 0.35 tonC/ha (5.3%), 0.96 tonC/ha (14.7%), 0.94 tonC/ha (14.5%), and 1.14 tonC/ha (17.5%), respectively. According to Park and Lee (1990), the net primary productions of stemwood, stembark, branch, foliage, and root in *Pinus densiflora* stand were 0.46 tonC/ha (13.1%), 0.14 tonC/ha (3.9%), 0.27 tonC/ha (7.6%), 2.08 tonC/ha (58.7%), and 0.23 tonC/ha (6.5%), respectively.

Table 9. Soil carbon contents of *Pinus densiflora* stand in Gongju, Yeoungdong, Chungsan, Muju, Mupung, and Jangsu, Korea.

Soil depth	Study area (tonC/ha)						
	Gongju	Yeongdong	Chungsan	Muju	Mupung	Jangsu	Average
0~10cm	13.09	4.85	7.32	10.72	39.86	7.52	13.89
10~20cm	8.19	4.42	3.39	6.53	28.91	5.75	9.53
20~30cm	5.63	4.04	2.44	4.20	28.33	4.64	8.21
30~50cm	3.49	5.72	13.70	7.47	35.37	5.47	11.87
Total(0~50cm)	30.4	19.03	26.85	28.92	132.47	23.38	43.51

4. Carbon content in soil

The soil carbon content in *Pinus densiflora* stand was 43.51 tonC/ha (Table 9). The value was lower than that of Lee (2007)'s study, in which soil carbon content was 65.8 tonC/ha in *Betula platyphylla* plantations and 47.0 t/Ca/ha in *Juglans mandshurica* plantations at 0-50cm soil depth. Also, they are lower than the findings of Park (1999). It reported the soil carbon content in a *Quercus mongolica* stand in Choongju area of Korea is 67.0 tonC/ha.

As shown in table 9, the biggest carbon accumulation is in the 0~10 cm because the 30-50cm range has double the volume of the 0-10cm range. Generally, it is known that carbon accumulation in soil is the highest at the surface, and decrease as depth increases because litterfall from aboveground and the fine roots at this depth may create plenty of organic matter (Armson, 1977).

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