J. Korean Soc. For. Sci. Vol. 108, No. 2, pp. 139~146 (2019)
https://doi.org/10.14578/jkfs.2019.108.2.139

한국산림과학회지
JOURNAL OF KOREAN SOCIETY OF FOREST SCIENCE
ISSN 2586-6613(Print), ISSN 2586-6621(Online)
http://e-journal.kfs21.or.kr

Carbon and Nitrogen Distribution of Tree Components in *Larix kaempferi* Carriere and *Quercus variabilis* Blume Stands in Gyeongnam Province

Choonsig Kim*

Department of Forest Resources, Gyeongnam National University of Science and Technology, Jinju 52725, Korea

Abstract: This study was conducted to determine the carbon (C) and nitrogen (N) distribution within tree components (i.e., stem, branches, leaves, and roots) of the Japanese larch (*Larix kaempferi* Carriere) plantation and natural oriental cork oak (*Quercus variabilis* Blume) stands. Fifteen Japanese larch and 15 oriental cork oak trees were destructively sampled to compare the C and N stocks in the components of the trees from three different regions—Hadong-gun, Hamyang-gun and Sancheong-gun—in Gyeongnam Province, South Korea. Species-specific allometric equations were developed to estimate the C and N contents in the tree components based on the diameter at breast height (DBH). There were differences in mean C and N concentrations between the Japanese larch and the oriental cork oak. The mean C concentrations of the tree componentswere significantly higher in Japanese larch than in oriental cork oak; whereas, the N concentration in the stems was significantly lower in Japanese larch than in oriental cork oak. The allometric equations developed for C and N content were significant (p < 0.05) with a coefficient of determination (R^2) of 0.76 to 0.99. The C and N stocks in the tree components do not appear to be affected by the species such as Japanese larch plantations and oriental cork oak stands. This study emphasizes the importance of C and N concentrations to estimate the C and N distribution according to tree components in different tree species.

Key words: *allometric equations, biomass, carbon and nitrogen stocks, Japanese larch, nutrient cycling, oriental cork oak*

Introduction

Understanding of the carbon (C) and nitrogen (N) distribution in tree components is important on the evaluation of nutrient dynamics because this information provide insights of nutrient uptake with assessing potential impacts of tree harvesting in forest stands (Balboa-Murias et al., 2006; Augusto et al., 2008; Temesgen et al., 2015). However, the tree C and N distribution is likely to be quite variable with forest types because tree species have different nutrient requirements, nutrient conversion rates and carbon allocation mechanisms (Balboa-Murias et al., 2006; Kim et al., 2017).

The C and N concentrations of tree components are determined by factors such as site conditions and forest management practices (Barron-Gafford et al., 2003; Tang et al., 2018), whereas the C and N contents of tree components were related to the biomass based on diameter at breast height (Paré et al., 2013; Kim et al., 2017). Thus, most of tree C and N contents in forest ecosystems are commonly estimated by using allometric equations (Bouvet et al., 2013; Kim et al., 2017). However, there is an inherent difficulty in using allometric equations to estimate the tree C and N content of forests because the C and N concentrations of tree components are closely related to the species differences (Paré et al., 2013; Kim et al., 201 7). Therefore, it is needed to develop the species-specific equations based on the C and N concentration of tree components.

Oriental cork oak (*Quercus variabilis* Blume) is one of the most naturally distributed deciduous hardwood species on Korean forest lands. Japanese larch (*Larix kaempferi* Carriere) is an important coniferous planting species with good growth characteristics throughout the country. Although

* Corresponding author
E-mail: ckim@gntech.ac.kr
ORCID
Choonsig Kim https://orcid.org/0000-0002-3263-1187

there have been many studies to evaluate the C and N stocks of biomass components in Korea (Kim, 1999; Lee et al., 2009; Noh et al., 2013; Kim et al., 2017), no studies are available to predict tree C and N stocks in Japanese larch plantations and oriental oak stands. This study was aimed to compare the C and N distribution of different tree components of Japanese larch and oriental oak stands in Gyeongnam Province.

Materials and Methods

1. Study site

The study was conducted in three Japanese larch plantations in two regions [Hamyang (HY1, HY2) and Sancheong (SC)] and natural oriental cork oak stands in two regions [Hadong (HD) and Sancheong (SC1, SC2)], located in the south-central part of Korea (Figure 1). The annual average precipitation and temperature are highest in HD, followed by SC and HY in the study area (Table 1). The soils in the study site are well-drained, brown forest soils (mostly Inceptisols or Alfisols, USDA Soil Taxonomy) originating from granite or granite gneiss with a loamy texture. The experimental design consisted of a 20 m × 20 m plot within each site. The stand density for Japanese larch plantations ranged from 225 to 1,025 trees ha^{-1}, whereas those for oriental cork oak ranged from 325 to 850 trees ha^{-1} (Table 1). The mean stand density was slightly higher for oriental cork oak (608 tree ha^{-1}) than

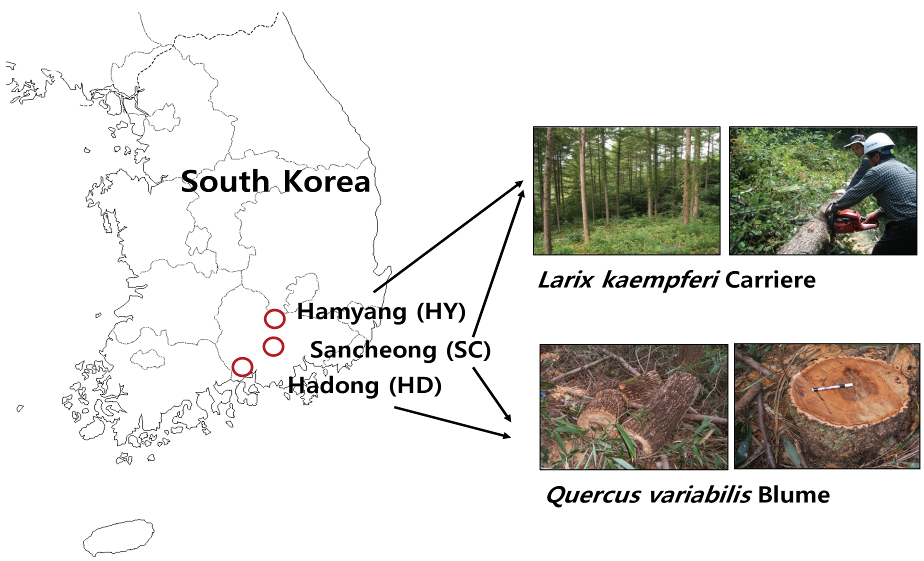

Figure 1. Location of the study site (Japanese larch, HY: Hamyang, SC: Sancheong; oriental cork oak, HD: Hadong, SC: Sancheong).

Table 1. General site and stand characteristics of Japanese larch plantations and oriental cork oak stands.

Tree species	Region	Location	Annual precipitation (mm)	Annual temperature (℃)	Aspect	Elevation (m)	Slope (°)	Parent rock	Stand density (Trees ha^{-1})	Basal area (m^2 ha^{-1})
Japanese larch	Hamyang1 (HY1)	35°27'30"N 127°38'18"E	1178	11.4	NE	623	15-20	Gneiss	500	28.4
	Hamyang2 (HY2)	35°27'26"N 127°58'28"E	1178	11.4	Nw	668	10-15	Gneiss	225	17.2
	Sancheong (SC)	34°24'15"N 127°48'46"E	1485	12.7	N	311	15-20	Gneiss	1025	24.8
Oriental cork oak	Hadong (HD)	35°13'13"N 127°44'06"E	1794	14.2	Nw	627	20-25	Granite	325	19.3
	Sancheong1 (SC1)	35°22'29"N 127°51'11"E	1485	12.7	Nw	471	25-30	Granite	650	21.4
	Sancheong2 (SC2)	35°22'27"N 127°51'12"E	1485	12.7	Nw	454	10-15	Granite	850	28.2

Table 2. General characteristics of sampled trees in Japanese larch and oriental cork oak.

Tree species	Region	Tree age (yrs)	DBH (cm)	Height (m)	Stem density (g cm^{-3})	Aboveground BEF	Total BEF
Japanese larch	Hamyang1 (HY1)	33 (0.3) [32-34]	24.2 (2.4) [18.2-30.8]	19.0 (0.3) [18.3-19.8]	0.45 (0.01) [0.43-0.50]	1.27 (0.06) [1.14-1.50]	1.72 (0.02) [1.70-1.74]
	Hamyang2 (HY2)	45 (1.2) [41-48]	30.6 (2.4) [23.7-37.6]	22.2 (1.3) [17.8-24.8]	0.47 (0.02) [0.41-0.53]	1.22 (0.03) [1.09-1.29]	1.62 (0.03) [1.59-1.65]
	Sancheong (SC)	30 (1.5) [24-32]	16.2 (2.3) [9.3-22.5]	15.5 (1.5) [10.5-18.5]	0.43 (0.01) [0.40-0.46]	1.18 (0.03) [1.11-1.24]	1.41 (0.08) [1.33-1.49]
	Mean	36 (1.9) [24-48]	23.7 (2.0) [9.3-37.6]	18.9 (1.0) [10.5-24.8]	0.45 (0.01) [0.40-0.53]	1.22 (0.45) [1.09-1.50]	1.58 (0.06) [1.33-1.74]
Oriental cork oak	Hadong (HD)	41 (3.2) [30-48]	26.5 (3.0) [17.6-36.4]	16.9 (1.6) [13.0-21.8]	0.66 (0.03) [0.53-0.72]	1.30 (0.06) [1.07-1.38]	1.92 (0.24) [1.68-2.16]
	Sancheong1 (SC1)	39 (2.0) [35-46]	20.2 (2.3) [13.9-26.6]	13.9 (0.9) [12.5-17.0]	0.56 (0.02) [0.53-0.62]	1.29 (0.03) [1.21-1.41]	1.63 (0.06) [1.58-1.70]
	Sancheong2 (SC2)	39 (1.4) [36-44]	20.2 (3.6) [11.4-30.8]	12.7 (1.5) [8.7-16.40]	0.67 (0.02) [0.63-0.73]	1.23 (0.04) [1.09-1.37]]	1.63 (0.14) [1.50-1.77]
	Mean	40 (1.3) [30-48]	22.3 (1.8) [11.4-36.4]	14.5 (0.9) [8.7-21.8]	0.63 (0.02) [0.53-0.73]	1.27 (0.03) [1.08-1.41]	1.73 (0.09) [1.50-2.16]

Values in parentheses are standard error. Values followed by brackets indicate range from maximum and minimum. DBH: diameter at breast height (1.2 m). Stem density: stem biomass/stem volumes. BEF: biomass/stem biomass.

for Japanese larch (583 tree ha^{-1}) stands. The mean tree age of Japanese larch (36 years) was slightly lower than for oriental cork oak (40 years) stands (Table 2).

2. Carbon and nitrogen of tree components

A complete tree inventory was carried out for each plot. Five sample trees based on the diameter at breast height (DBH) ranges in each plot were randomly chosen and were destructively sampled in August 2008. The sample trees are separated into components (i.e., leaves, branches and stems). The coarse roots (> 5 mm diameter) of two sampled trees within each plot were excavated using a machine. The fresh biomass for each tree component was determined in the field using portable electronic balances. Sub-samples from each tree component were taken to determine the fresh-to-oven-dried biomass ratio. All the investigations were carried out in accordance with technical standards formulated by the Korea Forest Research Institute (2010). The samples of each tree component were oven-dried at 85°C for one week, and the dried samples were ground in a Wiley mill. C and N concentrations from the ground materials were determined using an elemental analyzer (Thermo Scientific Flash 2000, Italy). The C and N contents of the tree components (stem, branches, leaf and roots) were calculated from C and N concentration and the biomass of each tree component.

The allometric equations [$\log_{10}y = a + b \times \log_{10}(DBH, cm)$] were developed for each tree component (stem, branch, leaf, roots): where y is the C or N content (kg) of the tree components, and a and b are regression coefficients. The accuracy of the allometric equations was evaluated by the coefficient of determination (R^2) and root mean square error (RMSE) (Socha and Wezyk, 2007). Bias correction factors (CF) in the logarithmic transformation were calculated using the standard error of the estimate (Garcia Villacorta et al., 2015). The C and N distribution (concentrations and stocks) of each tree component in both tree species was compared at $p < 0.05$ using the PROC T-test procedure of SAS (SAS Institute, 2003).

Results and Discussion

1. Carbon and N concentrations among tree components

The C concentration among tree components was not correlated with DBH ($p > 0.05$), except for the C concentration in the branches of Japanese larch (Figure 2) which was positively correlated with DBH ($r = 0.65$, $p < 0.05$). Similarly, previous studies found that C concentrations in tree components showed no patterns with increasing DBH of coniferous tree species (Lamlom and Savidge, 2006; Kim et al., 2017) because interspecific variations in the C concentration in tree components were attributed to differences in nutrient concentration (Kim et al., 2017), polyphenolic compounds, cellulose, sugar and starch concentrations (Martin and Thomas, 2013), rather than difference in tree size (DBH). In addition, the C concentration of stem in *Sequoiaderon giganteum* (Lamlom and Savidge, 2006) and *Pinus thunbergii* (Kim et al., 2017) was unaffected by the diameter growth rates. The reasons for the positive correlation between branches of the Japanese larch and DBH are not clear, but branches may contain abundant starch in the inner bark for the development of new shoots with increased DBH (Martin and Thomas, 2013). Similarly, branch C concentration in red pine was also correlated with growth factors ($r = 0.40$) such as DBH (Kim et al., 2017).

There were species-specific differences in mean C concentrations between Japanese larch and oriental cork oak (Table 3). The high C concentration in Japanese larch could be due to the intra-specific variation of the C concentration in the tree species determined by genetic factors (Bert and Danjon, 2006; Thomas and Martin, 2012; Martin et al., 2015). For example, C concentrations among tree components in both tree species could be attributed to the proportion of lignified wood tissues among tree species (Bert and Danjon, 2006). Chong and Park (2008) reported that the lignin concentration in stems was higher for

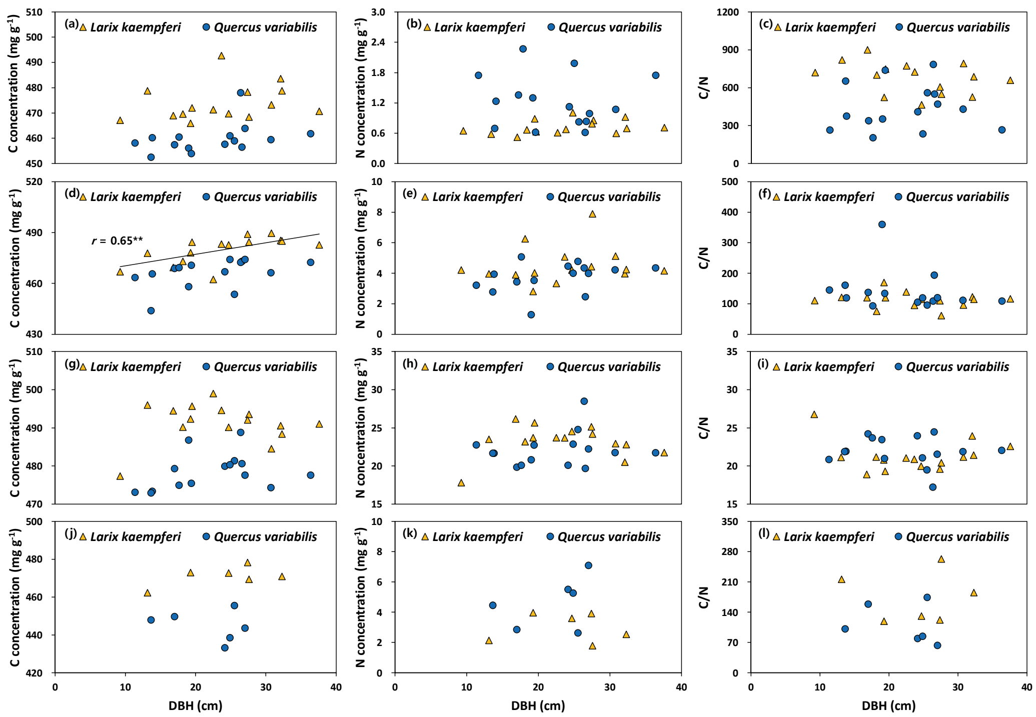

Figure 2. Correlation between carbon concentration, nitrogen concentration or C/N ratio and diameter at breast height (DBH) of tree components (stem: a, b, c; branches: d, e, f; leaf: g, h, i; roots: j, k, l) in Japanese larch plantations and oriental cork oak stands.

Table 3. Mean values of carbon and nitrogen concentration (mg g^{-1}) and C/N ratio for tree components in Japanese larch and oriental cork oak.

Nutrient	Tree species	Tree component			
		Stem	Branches	Leaf	Roots
Carbon	Japanese larch	474(1.87)	479(2.11)	491(1.34)	471(2.14)
	Oriental cork oak	460(1.51)	466(2.2)	478(1.2)	445(3.3)
	p-value	<0.001	<0.001	<0.001	<0.001
Nitrogen	Japanese larch	0.72 (0.04)	4.51 (0.32)	23.3 (0.53)	2.99 (0.38)
	Oriental cork oak	1.22 (0.13)	3.71 (0.25)	22.0 (0.58)	4.61 (0.69)
	p-value	0.002	0.06	0.12	0.07
C/N ratio	Japanese larch	680(32)	112(6.5)	21(0.5)	173(24)
	Oriental cork oak	440(47)	140(17)	22(0.5)	109(19)
	p-value	<0.001	0.14	0.40	0.07

Values in parentheses are standard error.

Japanese larch (28.58 %) than for oriental cork oak (23.10%). In this study, the mean C concentrations in stems were 474 mg kg^{-1} for Japanese larch and 460 mg g^{-1} for oriental cork oak. The values of Japanese larch were similar to a global mean value of 475±5 mg g^{-1} for wood C concentration (Thomas and Malczewski, 2007), whereas the C concentration in oriental cork oak was slightly lower than the global mean value. In addition, the C concentrations of stem, branch, leaf and root in both species were lower than the fixed C conversion factor (500 mg g^{-1}) used for the C content of tree biomass (Hunt et al., 2010).

There was no clear influence of DBH on the N concentrations of tree components in both species (Figure 2). The N concentration in tree components could be attributed to different site conditions on wide regional scales (Kim et al., 2017). Martin and Thomas (2013) reported that N concentration of tree components showed unimodal patterns with increasing DBH, not linear patterns. In contrast to this result, there was a negative relationship between N concentration and increasing DBH in tree stems because of an increased proportion of dead parts in trees with larger DBH (Augusto et al., 2008; Bouvet et al., 2013).

The mean N concentrations of tree components in Japanese larch were not significantly different for the respective components in oriental cork oak, except for stems (Japanese larch: 0.72 mg g^{-1}; oriental cork oak: 1.72 mg g^{-1}). The low N concentration in stems of Japanese larch could be due to the proportion of living parenchyma cells, which is lower in coniferous stems compared to hardwood tree species (Meerts, 2002). In contrast to the N concentration of stems, the N concentration in leaves did not differ between both tree species (Japanese larch: 23.3 mg g^{-1}; oriental cork oak: 22.0 mg g^{-1}). This result could be associated with deciduous coniferous characteristics in Japanese larch, not evergreen coniferous species. Generally, the N concentration in leaves is lower in evergreen coniferous species compared with hardwood species because coniferous species often occupy nutrient-poor sites (Meerts, 2002).

2. Allometric equations to estimate C and N content

The allometric equations to estimate C and N content for tree components were highly significant ($p < 0.001$). The allometric equations provided better fits of aboveground C and N content, ranging from 91 to 99% of the variation

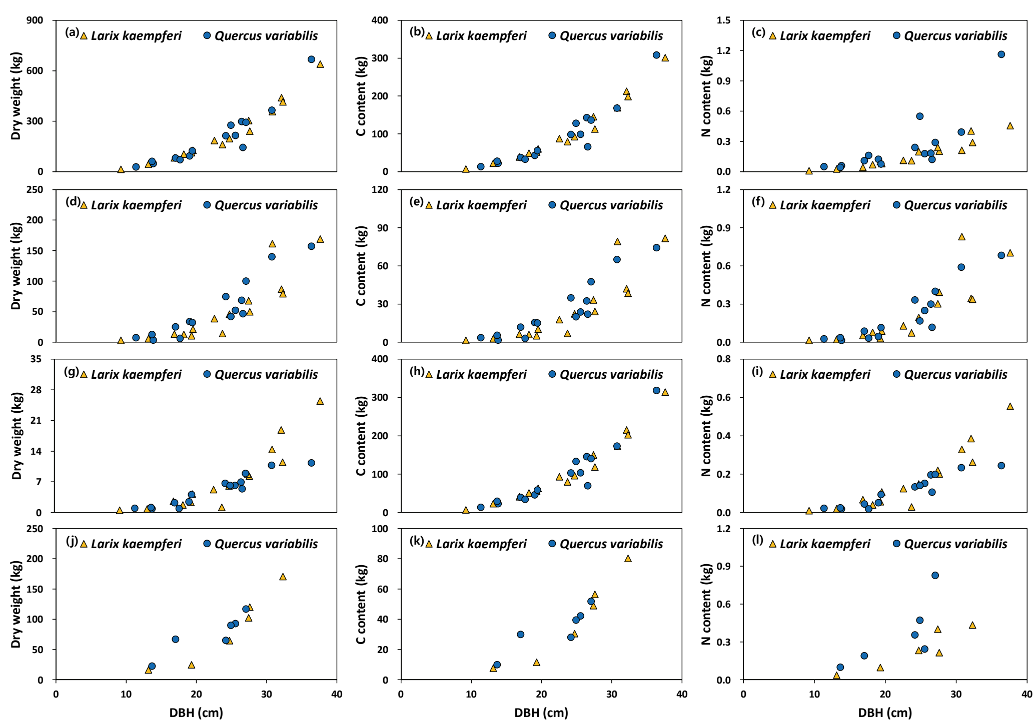

Figure 3. Scatter plots among dry weight, carbon or nitrogen content of tree components (stem: a, b, c; branches: d, e, f; leaf: g, h, i; roots: j, k, l) in Japanese larch plantations and oriental cork oak stands.

Table 4. Allometric equations for carbon and nitrogen content in tree components in Japanese larch and oriental cork oak.

Nutrient	Tree species	Tree component (y)	Regression coefficient		R^2	RMSE	p-value	CF
			a	b				
Carbon	Japanese larch	Stem (kg)	-1.6021	2.5883	0.99	0.0440	<0.0001	1.002
		Branches (kg)	-3.0419	3.1033	0.90	0.1769	<0.0001	1.037
		Leaf (kg)	-3.4926	2.8382	0.84	0.2124	<0.0001	1.053
		Aboveground (kg)	-1.6403	2.6816	0.99	0.0497	<0.0001	1.003
		Roots (kg)	-2.3620	2.8025	0.94	0.1151	<0.0001	1.015
		Total	-1.4406	2.6076	0.99	0.0505	<0.0001	1.003
	Oriental cork oak	Stem (kg)	-1.6238	2.5921	0.94	0.0958	<0.0001	1.011
		Branches (kg)	-3.2045	3.2975	0.81	0.2367	<0.0001	1.067
		Leaf (kg)	-3.4065	2.7357	0.88	0.1498	<0.0001	1.026
		Aboveground (kg)	-1.6561	2.6961	0.95	0.0953	<0.0001	1.011
		Roots (kg)	-1.0774	1.9160	0.79	0.1298	<0.0001	1.020
		Total	-1.0242	2.3488	0.98	0.0410	<0.0001	1.002
Nitrogen	Japanese larch	Stem (kg)	-4.6512	2.7550	0.97	0.078	<0.0001	1.007
		Branches (kg)	-5.2102	3.1990	0.87	0.2052	<0.0001	1.050
		Leaf (kg)	-4.8961	2.8953	0.85	0.2083	<0.0001	1.051
		Aboveground (kg)	-4.4589	2.9750	0.95	0.1141	<0.0001	1.015
		Roots (kg)	-4.6667	2.8671	0.95	0.1036	<0.0001	1.012
		Total	-4.4240	3.0648	0.98	0.0707	<0.0001	1.006
	Oriental cork oak	Stem kg)	-4.0275	2.4371	0.76	0.0440	<0.0001	1.049
		Branches (kg)	-5.5675	3.5632	0.84	0.2314	<0.0001	1.064
		Leaf (kg)	-4.7920	2.7705	0.86	0.1693	<0.0001	1.034
		Aboveground (kg)	-4.2157	2.8552	0.91	0.1296	<0.0001	1.020
		Roots (kg)	-3.7112	2.3843	0.77	0.1743	<0.0001	1.036
		Total	-3.9147	2.8407	0.93	0.1038	<0.0001	1.012

Allometric equation form is $\log_{10}y = a + b \times \log_{10}(DBH)$. The R^2 is the coefficient of determination. p-values represent the significance of the equations. RMSE: root means squared error. CF: correction factor.

compared with those of other tree components. However, the low values (0.84-0.88) of R^2 for C and N content of leaves could be due to the large scattering of leaf biomass (Figure 3) by different stand densities (Table 1). The slope values (b) of the allometric equations for C content of aboveground were similar between Japanese larch (2.6816) and oriental cork oak (2.6961). Although the physical differences in both tree species were apparent, the allometric coefficients (b) for C content of aboveground tree components was little influenced by both tree species. However, the slope values (b) of the allometric equations for N contents of tree components were generally higher in Japanese larch than in oriental cork oak, except for the branches (Table 4). This result indicated that the N content of tree components with similar DBH was higher in Japanese larch than in oriental cork oak.

3. Carbon and N stocks

Carbon and N stocks among tree components were not affected by tree species such as Japanese larch plantations and natural oriental cork oak stands (Table 5), although the N stocks in roots were marginally significantly higher ($p = 0.05$) in the oriental cork oak stand than in the Japanese larch plantation. Considerable differences in C stocks of stems were expected due to the difference in stem density (Japanese larch: 0.45 g cm^{-3}; oriental cork oak: 0.63 g cm^{-3}) in both tree species. However, significant changes in the total C and N stocks did not occur with both tree species because of the high C concentration of tree components in Japanese larch compared with oriental cork oak.

The mean value of aboveground C stocks was 62.97 Mg C ha^{-1} for Japanese larch plantations and 60.40 Mg C ha^{-1} for oriental cork oak stands and falls within the range established for a temperate forest in Korea. For example, the aboveground C stocks in Korea were 43.6 Mg C ha^{-1} for 31-year-old Japanese larch (Kim, 1999) and 69.1 Mg C ha^{-1} for a 50-year-old Quercus spp. (Lee et al., 2009).

Table 5. Mean values of carbon and nitrogen stocks (Mg ha^{-1}) for tree components estimated by allometric equations in Japanese larch plantations and oriental cork oak stands.

Nutrient	Tree species	Tree component					
		Stem	Branches	Leaf	Aboveground	Roots	Total
Carbon	Japanese larch	50.63 (7.18)	10.05 (1.74)	1.48 (0.23)	62.97 (9.20)	17.79 (2.72)	78.23 (11.16)
	Oriental cork oak	46.49 (4.98)	12.10 (1.50)	1.22 (0.13)	60.40 (6.51)	18.74 (2.25)	84.46 (9.17)
	p-value	0.66	0.42	0.38	0.83	0.80	0.69
Nitrogen	Japanese larch	0.080 (0.010)	0.097 (0.017)	0.070 (0.010)	0.253 (0.039)	0.110 (0.015)	0.366 (0.063)
	Oriental cork oak	0.113 (0.013)	0.123 (0.017)	0.056 (0.006)	0.280 (0.032)	0.193 (0.023)	0.530 (0.058)
	p-value	0.11	0.34	0.32	0.63	0.05	0.13

Values in parentheses are standard error.

The mean value (0.253 Mg N ha^{-1}) of N stocks in this study is similar to the value of 0.226 Mg N ha^{-1} for a 31-year-old Japanese larch plantation in Gyeonggi-do (Kim, 1999).

Conclusions

The C and N content of tree components in Japanese larch and oriental cork oak can be predicted by allometric equations using DBH as an independent variable. Although the C and N concentrations of tree components vary between both tree species, significant changes in the C and N stocks of tree components did not occur between Japanese larch plantations and oriental cork oak stands. Additional researches of intraspecific variation in C and N stocks are needed to be further investigated in order to yield the distribution patterns of nutrient stocks between coniferous plantations and natural hardwood stands. The results indicate that the measurement of C and N concentrations per tree components has been required for the C and N distribution in different tree species.

Acknowledgements

The author is grateful to the fieldwork member of soil lab at Gyeongnam National University of Science and Technology.

References

Augusto, L., Meredieu, C., Bert, D., Trichet, P., Porté, A., Bosc, A., Lagane, F., Loustau, D., Pellerin, S., Danjon, F., Ranger, J. and Gelpe, J. 2008. Improving models of forest nutrient export with equations that predict the nutrient concentration of tree compartments. Annals of Forest Science 65: 808.

Balboa-Murias, M.A., Rojo, A., Álvarez, J.G. and Merino, A. 2006. Carbon and nutrient stocks in mature *Quercus robur* L. stands in NW Spain. Annals of Forest Science 63: 557-565.

Barron-Gafford, G.A., Will, R.E., Burkes, E.C., Shiver, B. and Teskey, R.O. 2003. Nutrient concentrations and contents and their relation to stem growth of intensively managed *Pinus taeda* and *Pinus elliottii* stands of different planting densities. Forest Science 49: 291-300.

Bert, D. and Danjon, F. 2006. Carbon concentration variations in the roots, stem and crown of mature *Pinus pinaster* (Ait.). Forest Ecology and Management 222: 279-295.

Bouvet, A., Nguyen-The, N. and Melun, F. 2013. Nutrient concentration and allometric models for hybrid eucalyptus planted in France. Annals of Forest Science 70: 251-260.

Chong, S.H. and Park, B.S. 2008. Wood Properties of the Useful Tree Species Grown in Korea. No 29. Korea Forest Research Institute. pp. 390.

Garcia Villacorta, A.M., Martin, T.A., Jokela, E.J., Cropper Jr, W.P. and Gezan, S.A. 2015. Variation in biomass distribution and nutrient content in loblolly pine (*Pinus taeda* L.) clones having contrasting crown architecture and growth efficiency. Forest Ecology and Management 342: 84-92.

Hunt, S.L., Gordon, A.M. and Morris, D.M. 2010. Carbon stocks in managed conifer forests in Northern Ontario, Canada. Silva Fennica 44: 563-582.

Kim, C. 1999. Aboveground nutrient distribution in Pitch pine (*Pinus rigida*) and Japanese larch (*Larix leptolepis*) plantations. Journal of Korean Forestry Society 88 (2):

266-272.

Kim, C., Yoo, B.O., Jung, S.Y. and Lee, K.S. 2017. Allometric equations to asses biomass, carbon and nitrogen content of black pine and red pine trees in southern Korea. iForest 10: 484-490.

Korea Forest Research Institute. 2010. Survey Manual for Biomass and Soil Carbon. pp. 60.

Lamlom, S.H. and Savidge, R.A. 2006. Carbon content variation in boles of mature sugar maple and giant sequoia. Tree Physiology 26: 459-468.

Lee, S.K., Son, Y., Noh, N.J., Yoon, T.K., Lee, A.R., Seo, K.W., Hwang, J. and Bae, S.W. 2009. Carbon storage of pure and mixed pine-deciduous oak forests in Gwangneung, Central Korea. Journal of Ecology and Field Biology 32 (4): 237-247.

Martin, A.R. and Thomas, S.C. 2013. Size-dependent changes in leaf and wood chemical traits in two Caribbean rainforest trees. Tree Physiology 33 (12): 1338-1353.

Martin, A.R., Gezahegn, S. and Thomas, S.C. 2015. Variation in carbon and nitrogen concentration among major woody tissue types in temperate trees. Canadian Journal of Forest Research 45: 744-757.

Meerts, P. 2002. Mineral nutrient concentrations in sapwood and heartwood: a literature review. Annals of Forest Science 59: 713-722.

Noh, N.J., Kim, C., Bae, S.W., Lee, W.K., Yoon, T.K., Muraoka, H. and Son, Y. 2013. Carbon and nitrogen dynamics in a *Pinus densiflora* forest with low and high stand densities. Journal of Plant Ecology 6: 368-379.

Paré, D., Bernier, P., Lafleur, B., Titus, B.D., Thiffault, E., Maynard, D.G. and Guo, X. 2013. Estimating stand-scale biomass, nutrient contents, and associated uncertainties for tree species of Canadian forests. Canadian Journal of Forest Research 43: 599-608.

SAS Institute Inc. 2003. SAS/STAT Statistical Software. Version 9.1 SAS publishing Cary, NC.

Socha, J. and Wezyk, P. 2007. Allometric equations for estimating the foliage biomass of Scots pine. European Journal of Forest Research 126: 263-270.

Tang, Z., Xu, W., Zhou, G., Bai, Y., Li, J., Tang, X., Chen, D., Liu, Q., Ma, W., Xiong, G., He, H., He, N., Guo, Q., Zhu, J., Han, W., Hu, H., Fang, J. and Xie, Z. 2018. Patterns of carbon, nitrogen, and phosphorus concentration in relation to productivity in China's terrestrial ecosystems. PNAS 115 (16): 4033-3038.

Temesgen, H., Affleck, D., Poudel, K., Gray, A. and Sessions, J. 2015. A review of the challenges and opportunities in estimating above ground forest biomass using tree-level models. Scandinavian Journal of Forest Research 30: 326-335.

Thomas, S.C. and Malczewski, G. 2007. Wood carbon content of tree species in Eastern China: Interspecific variability and the importance of the volatile fraction. Journal of Environmental Management 85: 659-662.

Thomas, S.C. and Martin, A.R. 2012. Carbon content of tree tissues: A synthesis. Forests 3: 332-352.

Manuscript Received : January 10, 2019
First Revision : April 6, 2019
Accepted : April 8, 2019