Regular Article
pISSN: 2288-9744, eISSN: 2288-9752
Journal of Forest and Environmental Science
Vol. 32, No. 3, pp. 262-269, August, 2016
http://dx.doi.org/10.7747/JFES.2016.32.3.262

JFES
Journal of Forest and Environmental Science

Estimating Wood Weight Change on Air Drying Times for Three Coniferous Species of South Korea

Daesung Lee and Jungkee Choi*
Department of Forest Management, College of Forest and Environmental Sciences, Kangwon National University, Chuncheon 24345, Republic of Korea

Abstract

The purposes of this study are to calculate the green and dried weight using wood discs, to figure out weight change on air drying times, and to develop the model of wood disc weight change for *Larix kaempferi, Pinus koraiensis*, and *Pinus densiflora*. The variables affecting the weight change were investigated, and the pattern of weight change over time was figured out through linear models. When comparing the stem green weight calculated using wood discs in this study with the weight table of Korea Forest Service, the weight was not significantly different for *L. kaempferi* and *P. koraiensis*. On the other hand, in comparison of stem dried weight, the weight was significantly different in all of three species. In addition, various measurement factors were examined to figure out the relationship with weight change, and air drying times and disc diameter were found as significant independent variables. Finally, two linear models were developed to estimate air drying times of three species, fit statistics were significant for practical use.

Key Words: green weight, dried weight, moisture content, weight percentage, linear regression

Introduction

Wood weight and water content are evaluated as one of the fundamental factors with specific gravity and shrinkage rate in terms of wood processing (Kim 1995; Korean Standards Association 2001; Shin and Kim 2003; Korea Forest Research Institute 2008). In addition, timber trade by weight unit increased recently as the demand of log such as pulp increased (Korea Forestry Promotion Institute 2015). In Korea, the weight table is developed for main species using all the stem for green weight and wood disc for dried weight (Korea Forest Service 2009). At present *Larix kaempferi*, *Pinus koraiensis*, and *Pinus densiflora* are the main commercial tree species for wood production in South Korea (Korea Forest Research Institute 2012a, 2012b, 2012c). The total amount of timber produced per year is 638,135 m^3 for *L. kaempferi*, 826,587 m^3 for *Pinus* genus including *P. densiflora*, and 117,289 m^3 for *P. koraiensis* (Korea Forest Service 2014).

When these commercial trees are traded in the field, the wood weight change is not currently concerned. However, wood weight change should be considered for the accurate and reasonable trade. This is because wood weight is changed over time as decreasing the moisture content (Smith and Arganbright 1981; Simpson 2004). In other developed countries, many researches about estimating wood weight change on air drying times have been conducted (Peck et al. 1956; Simpson and Hart 2000; Simpson and Hart 2001; Simpson and Wang 2003). In Korea, there were studies on moisture content and shrinkage in relation to wood quality

Received: August 4, 2016. Revised: August 15, 2016. Accepted: August 19, 2016.

Corresponding author: Jungkee Choi
Department of Forest Management, College of Forest and Environmental Sciences, Kangwon National University, 188-77, Gonji-ro, Chuncheon 24345, Republic of Korea
Tel: 82-33-250-8337, Fax: 82-33-259-5617, E-mail: jungkee@kangwon.ac.kr

(Jung et al. 1986; Lee and Jung 1989; Lee and Lee 1993; Lee and Bae 2000; Lee and Kim 2001; Jang et al. 2012). However, there are no studies about estimating wood weight change on air drying times.

Therefore, the objectives of this research are to calculate green weight and air dried weight using wood discs, to investigate the variables affecting wood weight changes in the air dry condition, and to develop the wood weight change model for *L. kaempferi*, *P. koraiensis*, and *P. densiflora*.

Materials and Methods

Data collection

For this study, sample trees were collected from *L. kaempferi*, *P. koraiensis*, and *P. densiflora* stands in Gangwon, North Gyeongsang, and Gyeonggi provinces (Fig. 1). Total number of sites to collect sample trees was 69 sites: 45 sites for *L. kaempferi*, 16 sites for *P. koraiensis*, and 8 sites for *P. densiflora*.

From sample trees of the study sites, wood discs of a stem were collected in the same way of stem analysis. The sample tree, neither suppressed nor diseased, was cut at 0.2 m above the ground. From the fallen sample tree wood discs were collected at regular intervals, and the thickness of discs is 4 to 6 cm (Seo et al. 2015).

First wood disc (disc 1) was collected at 0.2 m above the ground, second disc (disc 2) at 1.2 m, third disc (disc 3) at 3.2 m, thereafter discs (disc 4, 5, 6, ···, n-1) at 2 m interval, and the last disc (disc n) was collected at 1 or 2 m interval (Fig. 2).

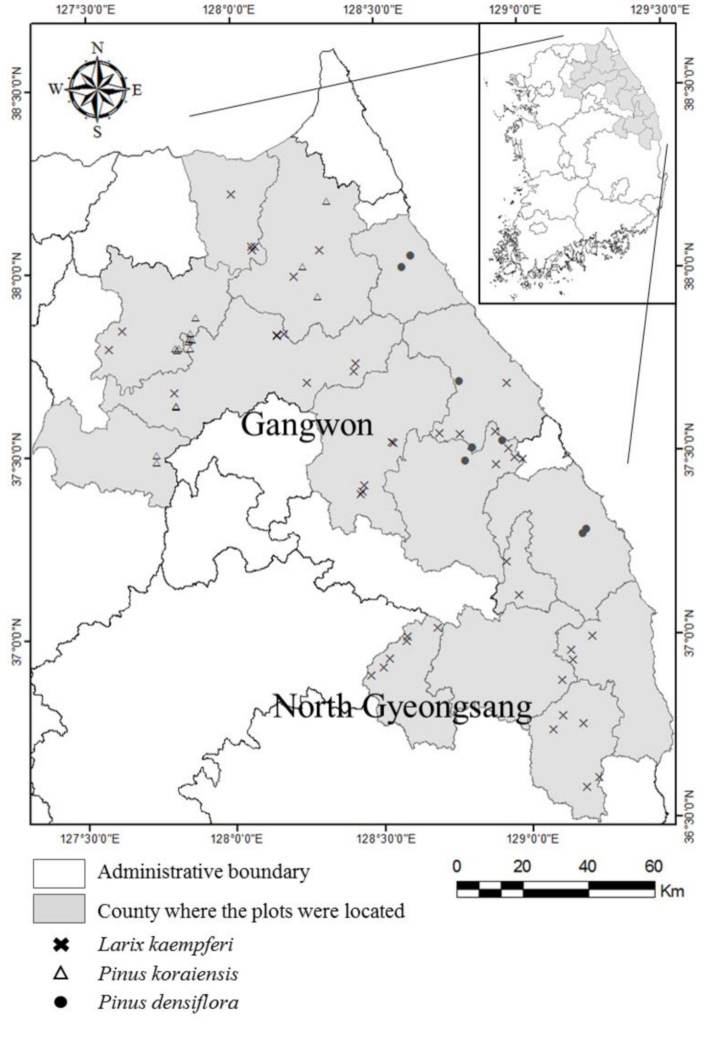

Fig. 1. Locations of sample trees for *Larix kaempferi*, *Pinus koraiensis*, and *Pinus densiflora*.

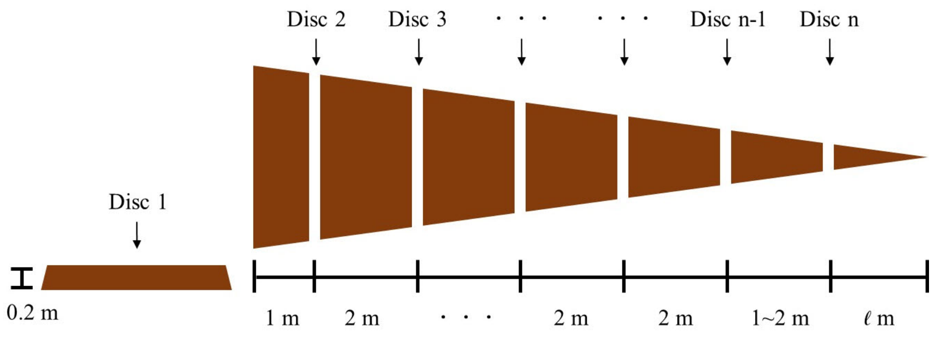

Fig. 2. Wood disc collection method for wood weight change study.

The summary statistics of sample trees used in this study is shown Table 1. Volume and green weight values were calculated by Smalian's formula. In addition, 6 to 16 wood discs per tree were collected for *L. kaempferi*, 6 to 13 wood discs per tree were collected for *P. koraiensis*, and 6 to 12 wood discs were collected for *P. densiflora*. By species the total number of wood discs was 531, 162, and 80, respectively.

Wood disc measurements

The discs of each species were used as materials for this study. The wood discs were measured at intervals of 1-2 week, 13-18 times for *L. kaempferi*, 16-17 times for *P. koraiensis*, and 16 times for *P. densiflora*. Wood discs were measured with the general weight scale. In total, the measurement period was 216-288 days for *L. kaempferi*, 163-181 days for *P. koraiensis*, 130 days for *P. densiflora*. Using the wood discs, stem weight was calculated in the same way of Smalian's formula. The wood weight on felling date was assumed as green weight. The wood weight of the last measurement was assumed as dried weight in this study because the wood disc weights remained constant after the 10th measurement.

Model development of wood weight change

In order to check the variables influencing the wood weight change, age, DBH, basal area, height of a tree, annual ring, diameter, disc area, height of discs, and air drying times were used as independent variables. Finally, linear regression models were selected for estimating weight change of wood discs. The parameters and coefficient of determination were computed using the PROC REG procedure in SAS 9.4 software (SAS Institute Inc. 2013).

In the process of model validation, coefficient of determination (R^2) and standard error of estimate ($S_{y\cdot x}$) were provided as indicators of fit. R^2 was typically used to provide all the functions with power of explanation about regression lines. $S_{y\cdot x}$ is an estimate of the variance about the regression, and examination of this statistic indicates that the smaller it is, the more precise will be the prediction (Draper and Smith 1981; Avery and Burkhart 2002). The equations were summarized as follows:

$$R^2 = 1 - \left[\sum_{i=1}^{n} (W_i - \widehat{W}_i)^2 \Big/ \sum_{i=1}^{n} (W_i - \overline{W})^2 \right]$$

$$S_{y\cdot x} = \sqrt{\sum_{i=1}^{n} (W_i - \widehat{W}_i)^2 / n-k}$$

Where W_i=measured weight for the i th disc, $\widehat{W}_i$=predicted weight for the ith disc, $\overline{W}$=measured mean disc weight, n=the total number of observations used in the model, k=the number of parameters.

Results and Discussion

Stem weight comparison

Stem green and dried weight of *L. kaempferi*, *P. koraiensis*, and *P. densiflora* were calculated from the wood discs of 45, 16, and 8 sample trees, respectively (Table 1). The sample trees had a diverse range in size. The sample trees ranged from 16 to 99 year of age, 15.8-47.9 cm in DBH, and 9.2-30.6 m in height. As a result of calculating volume and green weight through Smalian's formula, the sample trees ranged from 0.1002-2.2792 m^3 in volume and 100.5-1,667.8 kg in green weight.

Table 1. Summary statistics of sample trees

Species	Statistic	Age (year)	DBH (cm)	Height (m)	Volume (m^3)	Green weight (kg)
Larix kaempferi (n=45)	Mean	37.9	27.8	22.8	0.7498	584.1
	Maximum	60.0	47.9	30.6	2.2792	1,667.8
	Minimum	19.0	17.0	12.2	0.1587	126.3
	SD	12.6	8.0	4.5	0.5216	391.2
Pinus koraiensis (n=16)	Mean	44.3	30.4	18.3	0.7634	616.1
	Maximum	77.0	44.4	24.0	1.8518	1,555.8
	Minimum	16.0	15.8	9.3	0.1002	100.5
	SD	17.6	8.2	4.2	0.5209	386.2
Pinus densiflora (n=8)	Mean	58.8	36.3	17.9	0.9340	848.6
	Maximum	99.0	47.3	21.7	1.6693	1,491.2
	Minimum	34.0	23.7	9.6	0.2120	212.7
	SD	23.0	8.3	3.7	0.4940	414.2

Table 2. Comparison of stem green and dried weights between this study and Korea Forest Service (2009)

Species	Type of weight	Source	Mean	SD	Pr>T
Larix kaempferi	Green	This study	584.1	391.2	0.1826
		KFS	595.0	420.2	
	Dried	This study	379.1	272.7	0.0000
		KFS	308.1	216.7	
Pinus koraiensis	Green	This study	616.1	386.2	0.5047
		KFS	628.5	395.8	
	Dried	This study	323.5	233.0	0.0140
		KFS	281.9	182.1	
Pinus densiflora	Green	This study	848.6	414.2	0.0218
		KFS	755.9	346.8	
	Dried	This study	474.8	255.3	0.0071
		KFS	335.1	157.9	

To verify if there is no difference between the stem green weight using wood discs and the stem weight table by Korea Forest Service (KFS), t-test of paired comparison was performed for each species (Table 2). The t-statistic was not significant with $p=0.1826$ for *L. kaempferi* and $p=0.5047$ for *P. koraiensis* so that there was no difference between two studies. It proved that stem weight can be calculated from the several wood discs instead of a log. In the case of *P. densiflora*, the t-statistic was significant at the 5% level with $p=0.0218$. There was the difference between two studies unlike the case of *L. kaempferi* and *P. koraiensis*, which could be caused by the lack of samples.

For stem dried weight, t-test was also conducted, and the t-statistics were significant in all of three species ($p<0.05$). Thus, the difference was proven when compared to KFS. This was because KFS used oven dried weight and this study used air dried weight. Additionally, the weight ratio of dried wood to green wood in this study was compared with the weight ratio in the previous studies, and the weight ratios by species were similar (Forestry Research Institute 1994; Korea Forest Research Institute 2008; Korea Forest Service 2009).

Relationship of wood weight and measurement factors

In order to find out the pattern of weight change by losing the moisture of wood discs by species, the scatter plots of wood weight percentage over air drying days were displayed by the diameter class of wood discs (Fig. 3). Diameter class is based on the 5th National Forest Inventory Report (Korea Forest Research Institute 2011). The green weight

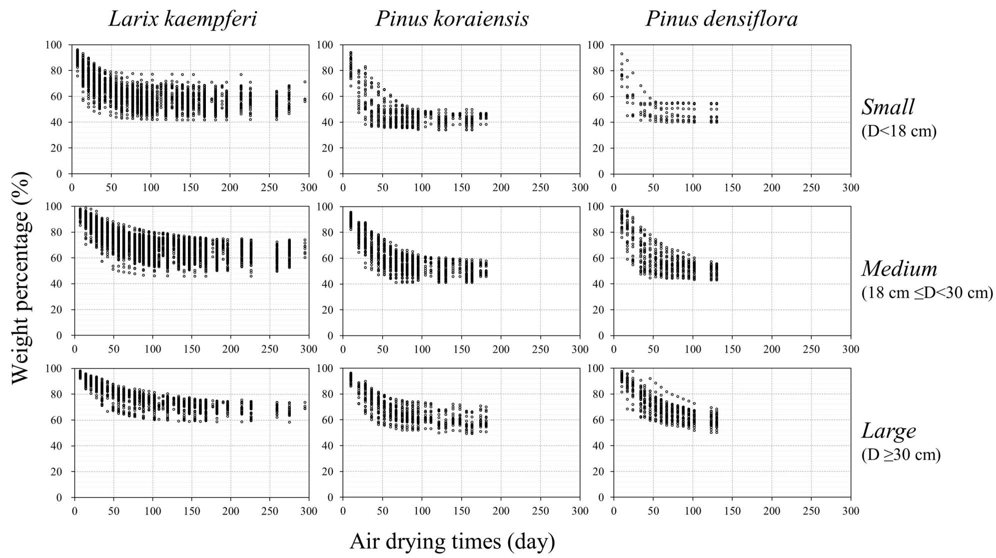

Fig. 3. Wood disc weight change (weight percentage) on air drying times (day) by diameter size class.

Table 3. Parameters and fit statistics in linear models of wood weight change

Species	DBH Class	Equation	n	Parameter			R^2	$S_{y \cdot x}$
				a	b	c		
Larix kaempferi	Small	1	2,023	102.6716	-9.4798		0.5557	7.5389
		2		83.3172	-9.5326	1.3623	0.6347	6.8374
	Medium	1	3,370	113.257	-9.7105		0.6438	6.3822
		2		98.8400	-9.7030	0.6209	0.6787	6.0628
	Large	1	1,236	114.9115	-8.8508		0.7507	4.5056
		2		112.1696	-8.8491	0.0742	0.7533	4.4831
Pinus koraiensis	Small	1	483	101.6573	-12.7343		0.5746	8.3326
		2		83.3006	-12.7763	1.2672	0.6117	7.9692
	Medium	1	1,041	120.9375	-14.4963		0.7312	6.5079
		2		92.4242	-14.5207	1.1811	0.8370	5.0703
	Large	1	596	118.0305	-12.1132		0.7017	5.7875
		2		107.8448	-12.1667	0.2826	0.7193	5.6193
Pinus densiflora	Small	1	126	95.0650	-10.9760		0.5023	7.7885
		2		65.6171	-10.9213	1.9938	0.5791	7.1916
	Medium	1	416	122.2099	-15.4826		0.6608	7.8195
		2		90.6525	-15.4826	1.3102	0.7843	6.2430
	Large	1	457	125.8545	-13.9443		0.7409	5.7364
		2		113.6927	-14.0346	0.3287	0.7706	5.4035

DBH class consists of Small (D < 18 cm), Medium (18 cm ≤ D < 30 cm), Large (D ≥ 30 cm); Equation 1 is WP = a + b × In (DAY) Equation 2 is WP = a + b × In (DAY) + c × Diameter WP is weight percentage (%); DAY is air drying days after felling from the field; Diameter (D) is size of wood disc diameter (cm); R^2 is coefficient of determination; $S_{y \cdot x}$ is standard error of estimate; a, b, c are parameter

was set as 100%, and the pattern of diminished weight was examined over air drying times.

In general, wood weight tended to decrease sharply in *P. koraiensis* and *P. densiflora* than in *L. kaempferi*. Also, the decreased range of weight percentage was wider in small and medium diameter class than in large diameter class.

The weight decreased down to 40% in small and medium diameter class while the weight retained 60% in large diameter class. The weights of each species had a tendency to decrease rapidly until 50 days after cutting. Also, the total amount of decreased weights before 50 days was larger than those after 50 days. Generally, the wood is likely to decrease the weight by losing its moisture in the beginning of air drying times, and this pattern was found in the previous studies (Simpson and Wang 2003; Simpson 2004).

Estimation of wood weight change

As a result of investigating various tree factors including age, DBH, height, and etc., air drying times and disc diameter were the most significant independent variables affecting weight change (Table 3). This is the same result with the previous studies in which these variables were used for the model development (Smith and Arganbright 1981; Simpson and Wang 2003).

In the regression equations using these variables, R^2 was higher in medium and large diameter class than in small diameter class in all of three species, and especially, R^2 of both Equation 1 and 2 increased in *L. kaempferi* as diameter class increased. The difference of R^2 was small between Equation 1 and 2 in all species, and the difference of standard error was also subtle. Also, all the parameters in linear models were significant ($p < 0.0001$).

As a result of model development, wood weight change by Equations was shown in Fig. 4. In the case of Equation 2, diameter was set to 10 cm in small class, 20 cm in medium class, and 30 cm in large class to display with air drying days over weight percentage. In comparison between species, percentage of weight decrease was relatively high in *P. koraiensis* and *P. densiflora*, and the lowest in *L. kaempferi*.

To figure out the air dried weight, the weights at 300 day were examined. On the basis of Equation 2, weight percentage by small, medium, and large class was 42.6%, 55.9%, 63.9% in *L. kaempferi*, 23.1%, 33.2%, 46.9% in *P. koraiensis*, and 23.2%, 28.5%, 43.5% in *P. densiflora*, respectively. In addition, the difference of weight percentage between Equation 1 and 2 was less than 9.2% in small class, 5.4% in medium class, and 2.8% in large class, and the difference was smaller as diameter class increased. Thus, both equations were considered to be appropriate for estimating the wood weight.

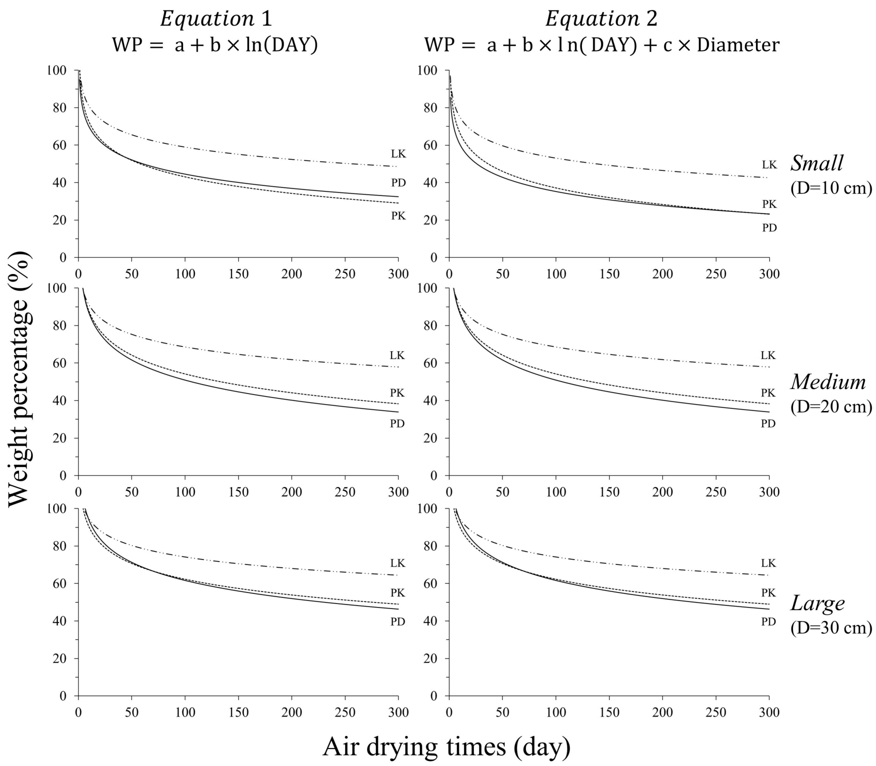

Fig. 4. Comparison of wood weight change on air drying times by species in linear models (LK, *Larix kaempferi;* PK, *Pinus koraiensis;* PD, *Pinus densiflora*).

Conclusion

This study was performed to calculate stem green weight and dried weight with collected wood discs, to estimate wood weight change on air drying times, and to develop the models of wood disc weight change for *L. kaempferi*, *P. koraiensis*, and *P. densiflora*. When comparing the stem green weight calculated using wood discs with the weight table of KFS, the weight was not significantly different at 5% level for *L. kaempferi* and *P. koraiensis*. On the other hand, in comparison of stem dried weight, the weight was significantly different at 5% level in all of three species.

With regard to the factors affecting the moisture content, air drying days after cutting influenced the most for wood weight loss. Also, the diameter size of a wood disc was found as a significant independent variable. The weight was found to decrease relatively high in the beginning of air drying times, especially before 50 days. Based on these research findings, two kinds of linear models were developed to explain wood weight change: model 1 used air drying days and model 2 used air drying days and disc diameter. Fit statistics indicated both models are suitable with high R^2 and low $S_{y \cdot x}$.

In this study, however, measurement factors were mainly examined from tree information, but meteorological and other factors should be considered to be added in further studies. Although there are limits of this research, it is still meaningful with regards to the finding of the patterns that how wood weight percentage decreases in natural conditions.

Acknowledgements

This study was carried out with the support of ‘full-time faculty research project (Project No. 120140267)’ funded by Kangwon National University in 2014 and the support of ‘The model development for management scale improvement of private forests in Korea (Project No. S111315L080110)’ funded by Korea Forest Service in 2015.

References

Avery TE, Burkhart HE. 2002. Forest Measurements. 5th ed. McGraw-Hill, Boston, pp 456.

Draper NR, Smith H. 1981. Applied Regression Analysis. 2nd ed. Wiley, New York, pp 709.

Forestry Research Institute. 1994. Wood Properties and Uses of the Major Tree Species Grown in Korea. Forestry Research Institute, Seoul, pp 270. (in Korea)

Jang JH, Kim JH, Kim NH. 2012. Variability of wood properties in stem of oriental white oak (*Quercus aliena* Blume) grown in research forest of Kangwon National University. J Res For Kangwon National University 32: 45-50. (in Korean with English abstract)

Jung HS, Han GS, Lee NH. 1986. Estimating moisture content losses of air-drying related to meteorological variables for Korean red pine and pitch pine. J Korean Wood Sci Technol 14: 7-13. (in Korean with English abstract)

Kim BR. 1995. Studies on variability in wood properties in tree stems of *Pinus koraiensis* (I) - differences in green moisture content and shrinkage between heartwood and sapwood -. J Korean Wood Sci Technol 23: 28-34. (in Korean with English abstract)

Korea Forest Research Institute. 2008. Wood Properties of the Useful Tree Species Grown in Korea. Korea Forest Research Institute, Seoul, pp 390. (in Korean)

Korea Forest Research Institute. 2011. The 5th National Forest Inventory Report. Korea Forest Research Institute, Seoul, pp 166. (in Korean)

Korea Forest Research Institute. 2012a. Commercial Tree Species 1 *Pinus densiflora*. Korea Forest Research Institute, Seoul, pp 250. (in Korean)

Korea Forest Research Institute. 2012b. Commercial Tree Species 3 *Pinus koraiensis*. Korea Forest Research Institute, Seoul, pp 168. (in Korean)

Korea Forest Research Institute. 2012c. Commercial Tree Species 4 *Larix kaempferi*. Korea Forest Research Institute, Seoul, pp 180. (in Korean)

Korea Forest Service. 2009. Volume • Weight Table • Yield Table. Korea Forest Service, Daejeon, pp 272. (in Korean)

Korea Forest Service. 2014. Production of Forest Products in 2013. Korea Forest Service, Daejeon, pp 590. (in Korean)

Korea Forestry Promotion Institute. 2015. The Domestic Timber Market Price Trends in Winter, 2014. Korea Forestry Promotion Institute, Seoul, pp 145. (in Korean)

Korean Standards Association. 2001a. Determination of Density and Specific Gravity of Wood. KS F 2198. Korean Standards Association, Seoul, pp 5. (in Korean)

Lee HW, Kim KY. 2001. Rapid moisture content determination technique using microwave oven. J Korean Wood Sci Technol 29: 16-24. (in Korean with English abstract)

Lee SB, Jung HS. 1989. Studies on predicting the kiln drying time and moisture content of board and dimension lumber of *Pinus densiflora* using an internal moisture diffusion model of softwood. J Korean Wood Sci Technol 17: 67-81. (in Korean with English abstract)

Lee SJ, Lee WY. 1993. Variation of green moisture contents in ma-

jor coniferous tree stem. J Korean For En 13: 37-43. (in Korean with English abstract)
Lee WH, Bae HM. 2000. Distribution of moisture content in wood with vapor transmission conditions. J Korean Wood Sci Technol 28: 3-9. (in Korean with English abstract)
Peck EC, Kotok ES, Mueller LA. 1956. Air drying of ponderosa pine in Arizona. For Prod J 6: 88-96.
SAS Institute Inc. 2013. SAS/STAT 9.4 User's Guide. SAS Institute Inc., Cary, NC.
Seo Y, Lee D, Choi J. 2015. Growth analysis of red pine (*Pinus densiflora*) by stem analysis in the eastern region of Korea. J For Environ Sci 31: 47-54.
Shin HH, Kim BR. 2003. Studies on variability in wood quality in stem of *Larix leptolepis* -green moisture content and shrinkage between heartwood and sapwood -. J Kor For En 22: 1-7. (in Korean with English abstract)
Simpson WT, Hart CA. 2000. Estimates of air drying times for several hardwoods and softwoods. General Technical Report FPL-GTR-121. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, pp 70.
Simpson WT, Hart CA. 2001. Method for estimating air-drying times of lumber. For Prod J 51: 56-63.
Simpson WT, Wang X. 2003. Estimating air drying times of small-diameter ponderosa pine and Douglas-fir logs. Research Paper FPL-RP-613. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, pp 14.
Simpson WT. 2004. Estimating air drying times of lumber with multiple regression. Research Note FPL-RN-0293. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, pp 6.
Smith WR, Arganbright DG. 1981. General drying characteristics of young-growth redwood dimension lumber. For Prod J 31: 44-49.