Partitioning of above and belowground biomass and allometry in the two stand age classes of *Pinus rigida* in South Korea

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Abstract: This study was conducted to determine the influence of age class on aboveground and belowground biomass partitioning and to develop allometric equations for the estimation of *Pinus rigida* biomass in South Korea. To determine the biomass of the stem wood, stem bark, branch and foliage, trees were harvested and roots were excavated, after which the dry weight of each biomass component was determined. Results showed that the mean biomass of *Pinus rigida* for stand 1 (<21 years) was 12.28kg, whereas the mean biomass for stand 2 (21-40 years) was 129.35kg. The proportion of stem wood biomass to total aboveground biomass increased from stand age class 1 (55.8%) to stand age class 2 (69.3%). Although stem biomass percentage tends to increase as stand age increase, it is not recommended to exclude secondary tree component biomass such as foliage, branches and roots, as this will significantly underestimate the total biomass and carbon storage potential of a forest. The mean root to shoot ratio for the two age classes were 0.20 and 0.26, respectively, and a high correlation was also observed between aboveground and belowground biomass tree components and the DBH. The highest R^2 value was observed in the total biomass with 0.99 for both stand age classes. It was also observed that the biomass tree component have different equation parameters and significant difference between the two age classes, and thus, the allometric equations developed should be applied based on the age of the stand.

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1. Introduction

Member countries are required to accurately assess the carbon stocks available in their forests, and figures for such carbon stocks are regularly reported as forest resources status, based on the United Nations Framework Convention on Climate Change (UNFCCC) (Basuki et al. 2009; Kim et al. 2011). Approximately, 80% of all aboveground carbon (C) and 40% of belowground C were reported to be stored in the forest biomass (Dixon et al. 1994). Furthermore, Lim et al. (2003) stated that carbon budgets, especially in forest ecosystems, are very important as they are considered as a major sink for carbon and have the potential to release this carbon in cases of deforestation and degradation. Because of the potential impact of forests to global climate change, carbon stock estimations for forest have become a major research interest (Watson et al. 2000; Lehtonen et al. 2004; Tobin and Nieuwenhuis 2007; Bollandsas et al. 2009; Teobaldelli et al. 2009; Li et al. 2010a). In order to determine the amount of carbon stored in a particular forest, biomass must be accurately estimated (Xiao and Ceulemans 2004; Fehrmann et al. 2008; Chung et al. 2009; Hosoda and Iehara 2010).

In 2010, Korea Forest Service (KFS) reported that the Republic of Korea (South Korea) has a total of 6.370 million ha of forest land, covering approximately 64% of the total land area (KFS 2010). Coniferous forests account for 2.672 million ha or about 42% of the total forest lands, and the third most dominant coniferous species in this country is *Pinus rigida* (Miller), belonging to the family Pinaceae. The species originated from North America (Mirov 1967; Kwon and Lee 2006). The land area covered by *Pinus rigida* in South Korea is approximately 0.41 million ha or 15.2% of the total coniferous forest area (Lee 2010), and hence, there is significant need to accurately estimate the biomass of this species.

In most forest inventories, diameter at breast height (DBH) of trees is measured. In order to use this existent data to estimate biomass, allometric equations must be developed. According to Teobaldelli et al. (2009), forest inventory data can be used to estimate biomass and carbon stocks in this manner. Furthermore, allometric regression equations can serve several other purposes, such as calculation of ecosystem properties like carbon, nutrient and water dynamics (Son et al. 2001). However, Kim et al. (2011) reported that the age of a stand has a great influence on the allometric factors. It was recommended that forest biomass must be calculated using site-specific (age) allometric equations. Studies have previously been conducted to develop allometric equations for biomass estimation of *Pinus rigida* in Korea (Kim 1999; Seo et al. 2006), however, there is still insufficient information on the effects of stand age on biomass partitioning and allometry. This study was conducted to determine the influence of stand age on aboveground and belowground biomass, and to develop allometric equations for biomass estimation in two stand age classes (< 21-year-old, 21- 40-year-old).

2. Material and Methods

Study sites

Study sites were located in various *Pinus rigida* plantations in South Korea. Coniferous forests dominate the forest land of this country with 2.672 million ha, or about 42% of forest coverage. Mixed forests account for 1.844 million ha or 29%, and broadleaved forests account for 1.66 million ha or 26% of forest coverage, with other types of forests accounting for 0.18 million ha or 3% coverage (KFS 2010). The majority of coniferous forest are dominated by *Pinus densiflora,* covering 1.48 million ha or 54.9% of the total coniferous forest lands. This is followed by *Larix kaempferi* and *Pinus rigida* with 0.46 million ha (17.2%) and 0.41 million ha (15.2%) coverage, respectively (Lee 2010).

South Korea has a temperate climate, with four distinct seasons. In the northern region, the annual mean temperature is 3º-10º Celsius while in the Central region and southern region it is 12º-14º Celsius, and the annual mean precipitation ranges from 600mm to 1600mm (Lee 2010).

Data collection and analysis

A total of 14 plots were established, eight of which were 10m by 10m while six were 20m by 20m. In each plot, one tree which represented the entire DBH range was harvested. Suppressed trees, wolf-trees, and the top-part damaged trees were not harvested. Sampled trees were felled 0.2m from the ground. The average age of the sampled trees in younger stands was 16 years, ranging from 11 to 20 years, whereas the average age observed for the older stands was 33 years, ranging from 21 years to 40 years. The mean DBH of the sampled trees for the younger and older stands were 6cm and 18cm and the mean total height of the sampled trees were 5m and 13m, respectively (Table 1).

Stem discs of 5cm thickness were collected from every 2m section of the stem, where the first and last discs were collected from the first and last 1m of the log. After collecting the discs, the remaining stems, or trunks, were weighed in order to determine the fresh weight. Different data were also collected from the discs, such as the diameter of the inside and outside bark. The oven-dry weight of the discs were then measured after disc samples were dried at 85^{o} Celsius until constant weights were observed. The dry weight and ratio of the dry weight to fresh weight of discs were then determined.

Table 1. Summary of the observed statistics for *Pinus rigida* stands in South Korea.

Age class	Stand 1 (<21 years)	Stand 2 (21-40 years)
n	6	8
Age(year)	16 (11~20)	33 (21~40)
DBH(cm)	6 (3~12)	18 (11~23)
Height(m)	5 (2~9)	13 (9~17)
Altitude(m)	189 (155~305)	246 (155~450)
Slope(˚)	11 (10~15)	14 (10~21)

Note: Mean values are represented with ranges in parenthesis.

The roots, or belowground biomass of the harvested trees were excavated using a fork crane. After removing soils from the roots, the total fresh weight of the belowground biomass was determined on site. Other biomass components, such as the branches and foliage were partitioned. The total fresh weight of branches and foliages in all sampled trees were determined. Furthermore, 350g samples of each biomass component, such as the branches, foliage and roots were then sampled, and were also dried at 85^{o} Celsius constant temperature for about 10~14 days. The dry weight of branches, foliages and roots, as well as ratios of dry to fresh weights were obtained. The ratio of belowground to aboveground (*R*) biomass was then calculated using the standard method of division, as suggested by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2006). These ratios can be easily applied to estimations of the belowground biomass of forests of the same species, for which only data for aboveground biomass exists.

In order to develop allometric equations, aboveground and belowground biomass (*Y*) were regressed with DBH (*X*) using a log-log (base 10) transformation (log $Y = a + b \log X$) (Son and Kim 1998; Son et al. 2001; Noh et al. 2010). This model form was used in this study because it was recommended by the Korea Forest Research Institute (KFRI 2006) for Korean tree species, and provides a simple, relevant and standardized measurement. Using coefficients of determination (R^2) and root mean square error (*RMSE*) values, the goodness of fit was calculated. The collected data were statistically analyzed using SAS 9.1(SAS Institute Inc. 2004). To correct for bias in log-transformed allometric equations, Sprugel correction factors (Sprugel 1983) were used (Son and Kim 1998; Son et al. 2001). To determine if there was a significant difference between the allometric equations developed for the two stand age classes, analysis of variance (ANOVA) was used. The null hypothesis was tested at a 95% level of confidence. Hence, to reject the null hypothesis for a one-tailed test, the *p*-value should be lower than 0.05.

3. Results and Discussion

Tree Biomass

The observed mean biomass of the different tree components, including total aboveground and belowground biomass are presented in Table 2. It was observed that the mean biomass of each tree component was higher in the older stand. The mean total biomass of the younger stand was 12.28kg/tree whereas for the older stand, it was 129.35kg/tree. The mean aboveground biomass for the two stand age classes were 10.30kg/tree and 103.70kg/tree, respectively, where the mean belowground biomass were 1.98kg/tree and 25.66kg/tree. As expected, it was observed that in both stand age classes, stems accounted for the greatest proportion of total biomass with 6.78kg/tree and 82.35kg/tree, respectively.

Table 2. Partitioning of the trees component biomass of the two stand age classes of *Pinus rigida* in South Korea.

Tree component	Biomass(kg/tree)	
	Stand 1	Stand 2
Stem	6.78 (± 8.44)	82.35 (± 54.85)
Stem wood	5.74 (± 7.30)	71.90 (± 49.06)
Stem bark	1.04 (± 1.14)	10.44 (± 5.86)
Branch	2.09 (± 1.86)	14.29 (± 10.92)
Foliage	1.43 (± 1.24)	7.04 (± 2.91)
Above-ground	10.30 (± 11.07)	103.70 (± 67.11)
Root	1.98 (± 2.03)	25.66 (± 14.76)
Total	12.28 (± 13.09)	129.35 (± 80.72)

Note: Values are mean with standard deviation in parenthesis.

The proportion of canopy biomass, or the sum of the foliage and branch biomass were 34% and 21% for the younger and older age classes, respectively. Based from these results, it is not recommended to exclude secondary tree component biomass such as foliage, branches or roots, as this will significantly underestimate the total biomass and C storage potential of a forest (Peichl and Arain 2007).

The biomass distribution of the different aboveground tree components of stand 1 were 55.8% for stem wood, 20.3% for branches, 13.8% for foliage and 10.1% for stem bark, while the biomass distribution in stand 2 was 69.3%, 13.8%, 10.1% and 6.8% for stem wood, branches, stem bark and foliage, respectively (Figure 1). Results showed that stand age has a significant influence on tree biomass partitioning. The contribution of stem wood to the total aboveground biomass increased from the younger stand to the older stand. However, this was not the case for foliage and branches. It was observed that the contribution of foliage and branch biomass to total aboveground biomass decreased from stand 1 to stand 2. These results are similar to those of previous studies indicating that as stand age increases, the relative proportion of stem wood biomass increases, whereas the relative proportion of foliage and branch biomass decreases (Noh et al. 2010; Peichl and Arain 2007). It was also observed for the older stand that the relative proportion of stem bark biomass was higher than that of foliage biomass. This result is similar to that of Noh et al. (2010) on the partitioning of *Pinus densiflora* in Korea, where stem bark biomass was also higher than foliage biomass, particularly in the 44-year-old and 71-year-old stands of the study. Furthermore, Kim (1999) reported that the biomass distribution pattern of 31-year-old *Pinus rigida* stands was 69% for stem wood, 16% for branch, 11% for stem bark and 4% for foliage.

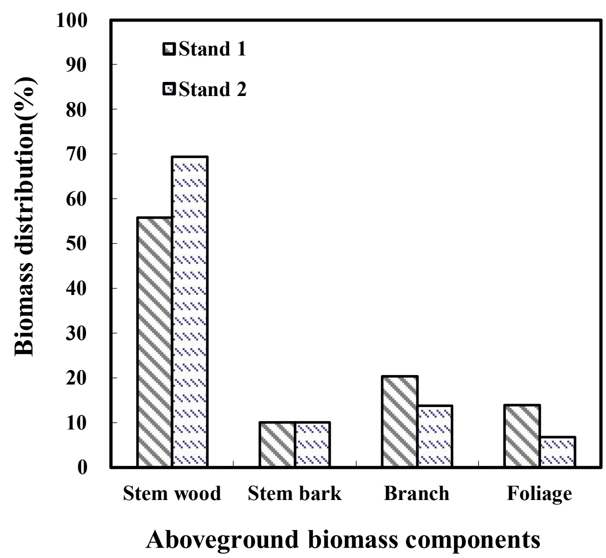


Figure 1. Comparison of the distribution (%) of tree component biomass to the total aboveground biomass between the two stands of *Pinus rigida* in South Korea.

The contribution of root biomass to total biomass for the two age classes increased with age, as 16.1% for stand 1 and 19.8% for stand 2 (Figure 2). Noh et al. (2010) reported that root biomass percentage of *Pinus densiflora* in Korea increased as stand age increased, with 17.6% observed for a 10 year old stand, and 20.8% observed for a 71 year old stand. It was observed that the proportion of branch biomass is higher compared to the proportion of root biomass in younger stands. This result differs compared to the study of Noh et al. (2010) which reported that root biomass was greater than branch biomass. Seo et al. (2006) also reported that *Pinus rigida* stands of less than 21 years have a greater relative proportion of root biomass (18.7%) than branch biomass (13.2%). This may be due to poorer site conditions of the younger stands in this study. According to Noh et al. (2010), site condition can strongly influence the allocation of biomass.

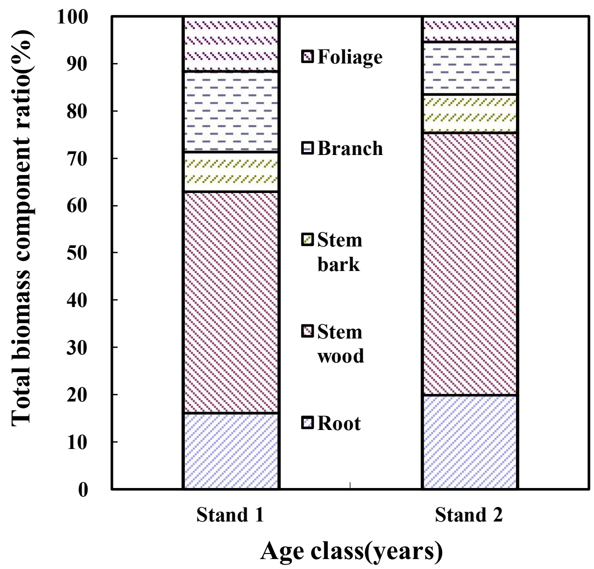


Figure 2. Partitioning of biomass aboveground and belowground in the two stands of *Pinus rigida* in South Korea.

The mean ratio of the belowground and aboveground biomass, or *R,* of the six trees sampled from younger stands was 0.20 whereas for the eight trees of older stands, it was 0.26. The mean *R* of all trees was 0.23. Seo et al. (2006) reported that the *R* of *Pinus rigida* for stands of less than 21 years was 0.18, 0.24 for 21-year-old to 40-year-old stands, and 0.15 for stands older than 40 years. One of the limitations of the present study is that it did not analyze stands older than 40 years. Koch (1989) reported that the average *R* of the main species in America was 0.17. Furthermore, Cairns et al. (1997) suggested that *R* values generally ranged from 0.2 to 0.3 while Whittaker and Marks (1975) reported that the average *R* value is 0.2. In South Korea, the KFRI suggested that the *R* value for coniferous species is 0.28, and 0.41 for the broadleaf species (KFRI 2008). Most *R* values suggested by previous literature are comparable with the results of this study. Accurate *R* values for a particular species are important because these values allow forest managers to easily estimate belowground biomass where only aboveground biomass data is available. According to Li et al. (2010b), belowground biomass is usually estimated by applying *R* values to the aboveground biomass or by using allometric equations, because direct field measurement of belowground biomass is very time consuming, laborious and difficult. Furthermore, the IPCC (IPCC 2006) suggested that country-specific *R* values can be used to estimate belowground biomass for mass calculations. An allometric equation was also developed to determine the linear relationship between the belowground and aboveground biomass and it is shown in Figure 3. The R^2 for this equation was 0.91.

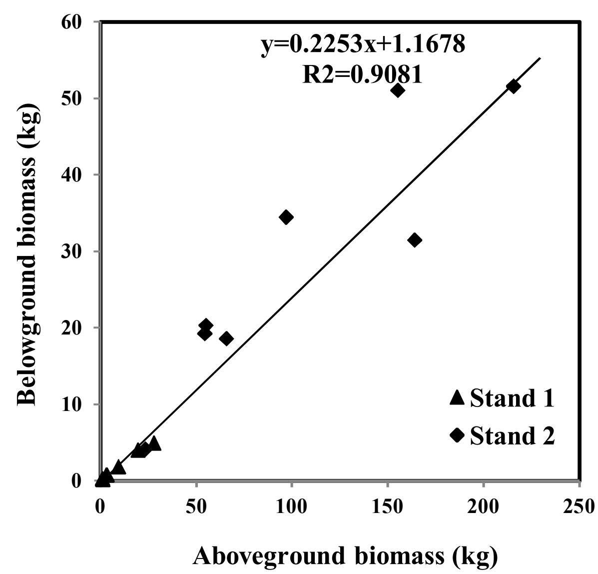


Figure 3. Relationship between aboveground and belowground biomass of *Pinus rigida* in the two stands in South Korea.

Allometic equations

Allometric equations were developed to estimate total biomass and different tree component biomass using DBH values. Results are presented in Table 3. A high correlation was observed from the different aboveground and belowground biomass tree components to DBH. The highest R^2 was observed for aboveground biomass in stand 1 with 0.997 correlation between the calculated and estimated values observed for both stand age classes. The lowest R^2 was observed for foliage estimations, which was 0.862 for stand 1, and 0.734 for stand 2. It was also observed that biomass tree components have different equation parameters in the two age classes.

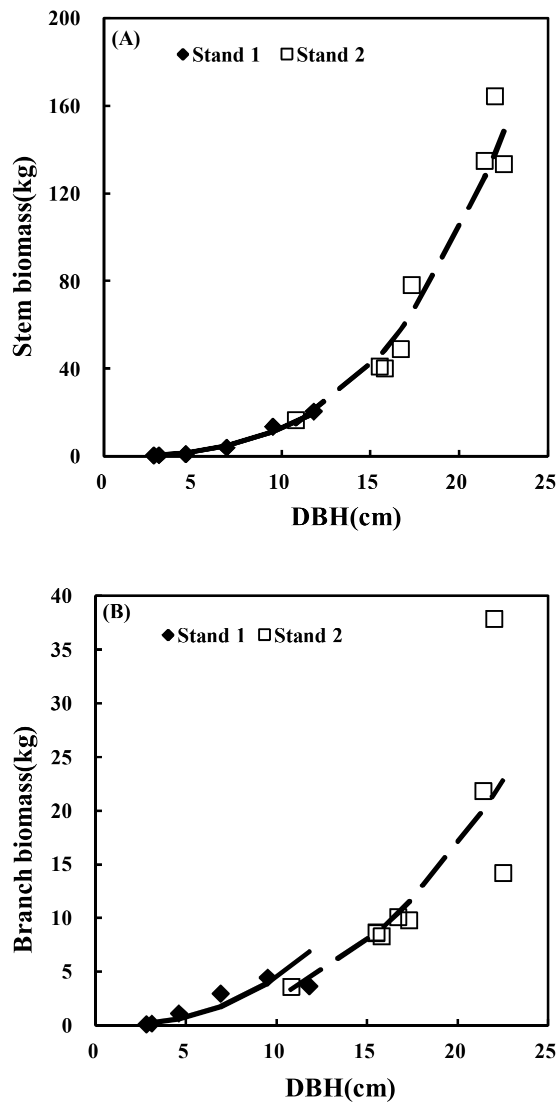
Table 3. Biomass equations* for the tree component biomass of the two stands of *Pinus rigida* in South Korea.

Tree component	*a*	*b*	*RMSE*	R^2	*SEE*	*CF*
Stand 1						
Stem	-3.542	2.642	0.270	0.977	0.135	1.009
Stem wood	-3.888	2.714	0.318	0.970	0.159	1.013
Stem bark	-4.632	0.316	0.139	0.992	0.069	1.002
Branch	-4.368	2.550	0.563	0.900	0.282	1.040
Foliage	-2.832	1.624	0.430	0.862	0.215	1.023
Above-ground	-2.585	2.441	0.093	0.997	0.046	1.001
Root	-4.198	2.427	0.407	0.939	0.204	1.021
Total	-2.391	2.433	0.136	0.993	0.068	1.002
Stand 2						
Stem	-4.822	3.154	0.171	0.959	0.070	1.002
Stem wood	-5.266	3.257	0.187	0.955	0.076	1.003
Stem bark	-5.056	2.541	0.095	0.940	0.039	1.001
Branch	-5.050	2.626	0.314	0.829	0.128	1.008
Foliage	-2.357	1.484	0.235	0.734	0.096	1.005
Above-ground	-3.991	2.952	0.170	0.954	0.069	1.002
Root	-5.986	3.161	0.263	0.909	0.107	1.006
Total	-2.381	2.428	0.129	0.994	0.053	1.001

* Equations follow the form $\log Y = a + b \log X$, where X is DBH (cm) and Y is biomass(kg), *RMSE* is root mean square error, R^2 is coefficient of determination, *SEE* is the standard error of estimate and *CF* is Sprugel correction factor.

Furthermore, results of ANOVA showed that there was significant difference between the aboveground biomass allometric equation of stand 1 and stand 2 and belowground biomass allometric equation of stand 1 and stand 2, with *p*-values of 0.005 and 0.003, respectively. Similar results were observed for the total biomass estimations through the allometric equations for stand 1 and stand 2, with a *p*-value of 0.005. Thus, it is recommended that the individual allometric equations developed in this study should be applied based on the age of the site. The *RMSE* ranged from 0.093 to 0.563 for stand 1 and 0.095 to 0.314 for stand 2. The standard estimation of error (*SEE*) observed in this study ranged from 0.046 to 0.282 in stand 1, and from 0.039 to 0.128 in stand 2. The highest *CF* was observed for branches (1.04) while the lowest *CF* was observed for the aboveground biomass allometric equation for stand 1 (1.001). For stand 2, the lowest *CF* was determined for stem bark and total biomass allometric equation with 1.001 and the highest was found in branches (1.008). The observed value of the different tree components of biomass, total aboveground biomass, belowground biomass and total biomass were fitted to the predicted values using the allometric equations that was developed (Figure 4).

The results of this study are significant in the assessment of biomass and carbon stocks in the pitch pine forests of South Korea. Furthermore, the developed allometric equations can be applied to estimate the pitch pine forests total biomass in South Korea using the 5th National Forest Inventory data.



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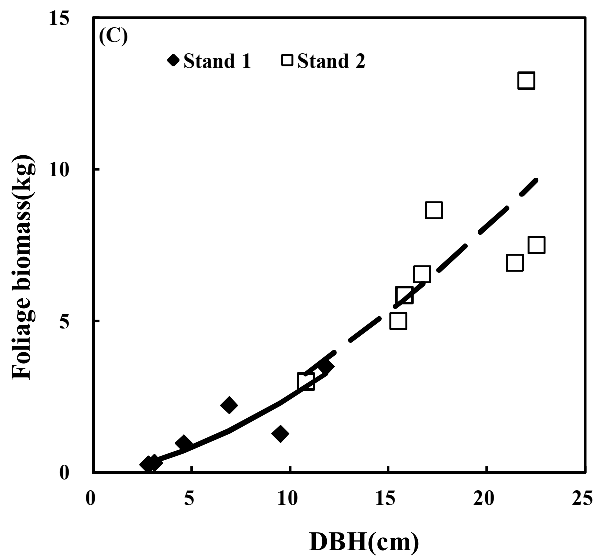

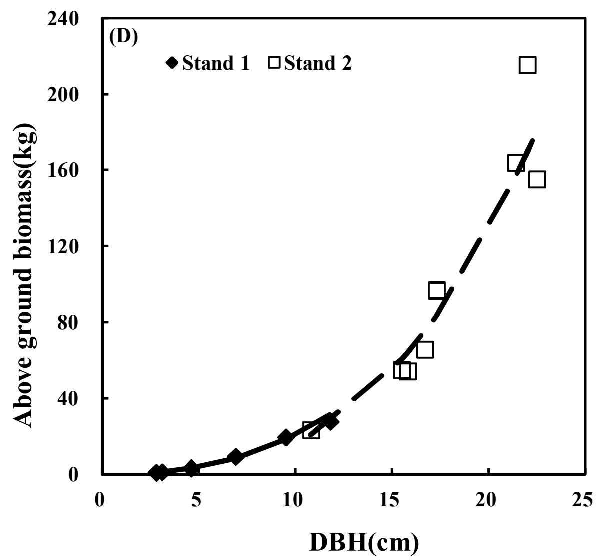

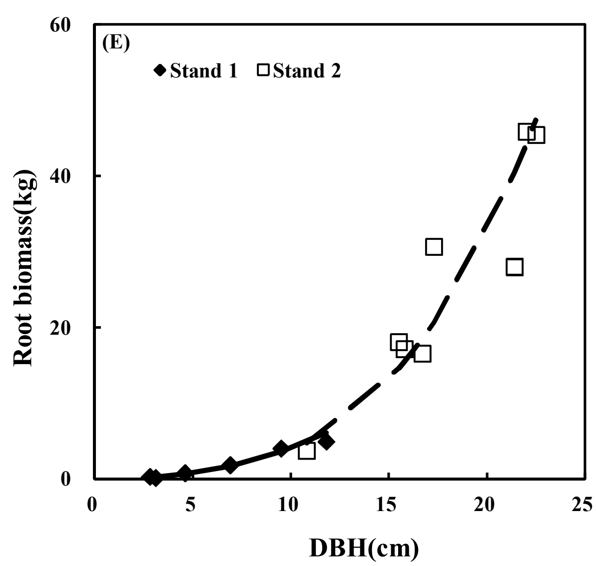

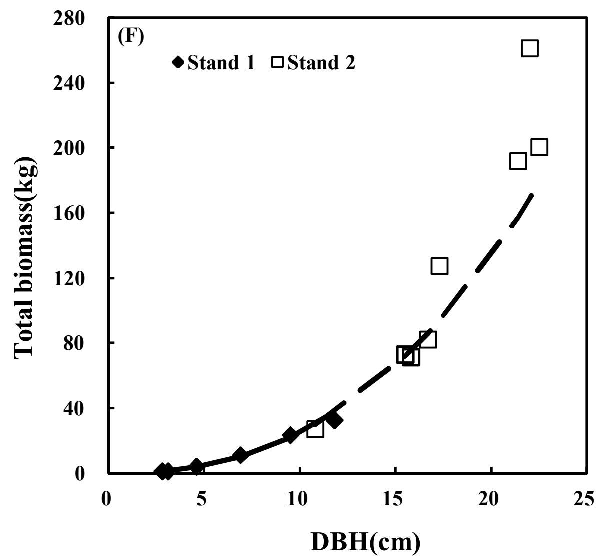

Figure 4. Relationships between the biomass and DBH in two stand age classes of *Pinus rigida* in South Korea.

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