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Growth Analysis of Red Pine (*Pinus densiflora*) by Stem Analysis in the Eastern Region of Korea

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Abstract

The study was performed to analyze the growth of the red pine (*Pinus densiflora*) in the Eastern Region of Korea. Stem profile data from a total of 8 dominant trees of which each tree represents its site were collected and used for the analysis. The stem volumes were calculated using Smalian's formula and much higher than the ones by Korea Forest Research Institute in larger than dbh 40 cm. The total bark volumes were more proportionally related to dbh and stem volume than to height and age. The bark thickness and volume decreased as relative height increases but increased as relative dbh increased. The average PAI of dbh and height reached the highest at 0.8 cm/yr (age 15) and at 0.45 m/yr (age 30) respectively, while the average PAI of volume steadily tended to increase up to age 80. The growth percentages of dbh, height and volume tended to decrease with age and volume growth percentage was higher than dbh and height.

Key Words: bark thickness, diameter growth, height growth, volume growth, periodic annual increment (PAI)

Introduction

Stem analysis is widely used for identifying the growth patterns of dbh, height and volume of individual trees and predicting their future growth (Lee 1995). Also the past growth of a stand which shows how a stand grew in diameter, height and volume is estimated by a stem analysis of standard trees in the stand.

Few studies have been conducted on growth patterns of the red pine by stem analysis in Korea. These studies can be classified into dbh growth pattern (Song 1995; Son et al. 2004; Lee et al. 2009), height and taper form (Kwak et al. 2004), site index and density (Yim 1970), and bark volume (Kim et al.1967; Son et al.1998). Meanwhile there is no research on the individual growth pattern of dbh, height and volume, especially of the red pine, by stem analysis.

Meanwhile, red pine (*Pinus densiflora*) in Korea grows very well even on a barren land and has been planted nationally as one of major commercial tree species since 1970s (Korea Forest Research Institute 2012a). Including natural red pine forests it consists about 22% of total forests in Korea (Korea Forest Service 2013). As it is expected to play a key role on domestic wood supply and utilization in the future, more attentions should be paid on how to manage the red pine trees.

Therefore this study aims to analyze the growth patterns of *Pinus densiflora* by stem analysis, focusing on bark volume, dbh, height and volume growth.

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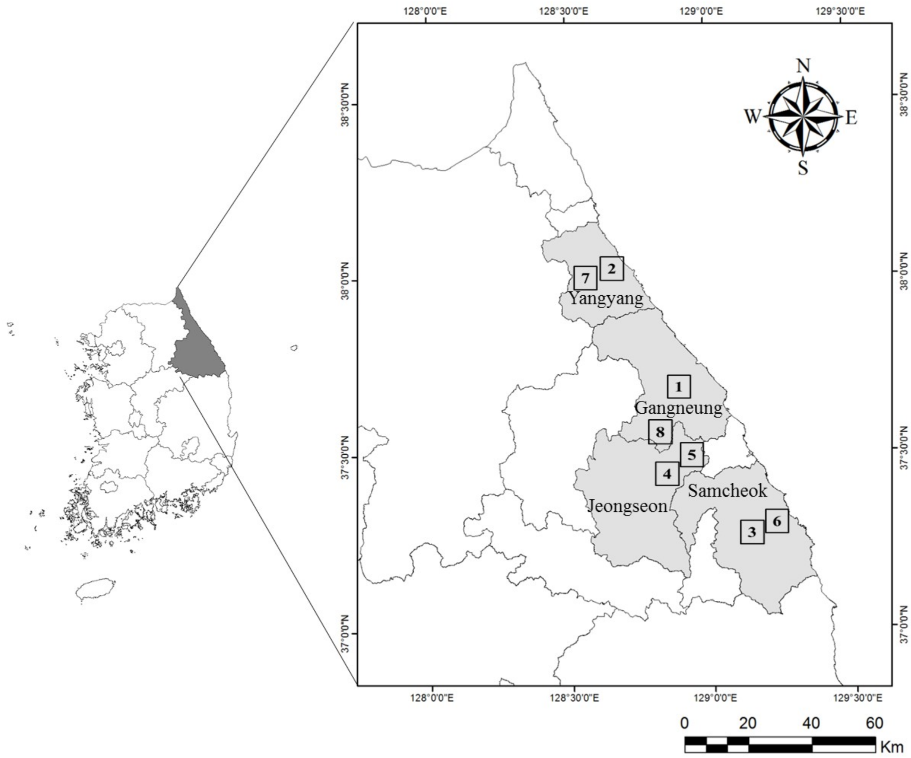

Fig. 1. Map of 8 permanent plots for red pine in the Eastern Region of Korea.

Table 1. Summary of 8 permanent plots for *Pinus densiflora*

Site	Slope aspect (°)	Slope gradient (°)	Trees (N/ha)	Tree			Stand		
				DBH (cm)	Height (m)	Volume (m^3)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index
1	316	21	475	22.3±6.7 (10.2-36.9)	14.5±2.6 (5.3-16.8)	0.277±0.165 (0.022-0.601)	20	132	16
2	252	18	1,675	15.0±4.6 (6.4-24.8)	9.0±2.5 (3.8-14.9)	0.089±0.063 (0.007-0.240)	32	148	12
3	250	24	725	26.5±11.6 (8.7-52.3)	16.4±3.1 (10.0-21.9)	0.501±0.473 (0.036-1.833)	48	363	18
4	292	37	875	23.8±6.0 (12.2-34.8)	14.2±2.7 (8.1-19.0)	0.306±0.170 (0.050-0.690)	41	268	14
5	260	16	425	33.7±5.6 (23.5-47.5)	18.4±1.8 (15.4-22.5)	0.695±0.232 (0.335-1.188)	39	296	16
6	280	30	450	29.4±6.3 (14.5-41.2)	16.0±1.7 (13.1-18.5)	0.498±0.228 (0.113-0.975)	31	212	14
7	290	22	750	26.1±4.3 (19.5-34.3)	14.5±1.4 (11.4-17.5)	0.344±0.120 (0.171-0.568)	41	258	12
8	170	34	600	34.2±7.2 (22.9-50.2)	15.9±1.7 (11.7-18.7)	0.633±0.294 (0.258-1.450)	57	380	12

1, Godan-ri, Wangsan-myeon, Gangneung-si; 2, Sangwangdo-ri, Sonyang-myeon, Yangyang-gun; 3, Hama-eup-ri, Nogok-myeon, Samcheok-si; 4, Bancheon-ri, Imgye-myeon, Jeongseon-gun; 5, Jigwon-ri, Imgye-myeon, Jeongseon-gun; 6, Dongmak-ri, Geundeok-myeon, Samcheok-si; 7, Su-ri, Seo-myeon, Yangyang-gun; 8, Eoheul-ri, Seongsan-myeon, Gangneung-si.

Table 2. Characteristics of the stem-analyzed red pine trees from 8 permanent plots

No	Age (years)	DBH (cm)	Height (m)	Stem volume		Bark		Form factor
				Our study	KFRI (2012b)	Volume (m^3)	Ratio (%)*	
1	34	26.9	17.6	0.4686	0.4291	0.0315	6.7	0.47
2	41	23.7	9.6	0.2120	0.1856	0.0276	13.0	0.50
3	44	37.2	16.5	0.7231	0.7311	0.0709	9.8	0.40
4	48	32.7	19.6	0.8057	0.6840	0.0490	6.1	0.49
5	56	39.6	21.7	1.4072	1.0792	0.0721	5.1	0.53
6	61	37.9	20.4	0.8758	0.9353	0.0338	3.9	0.38
7	87	47.3	19.6	1.6424	1.3585	0.1226	7.5	0.48
8	99	45.4	18.2	1.3103	1.1685	0.0983	7.5	0.44

*Ratio (%)=(Bark volume/Stem volume)x100.

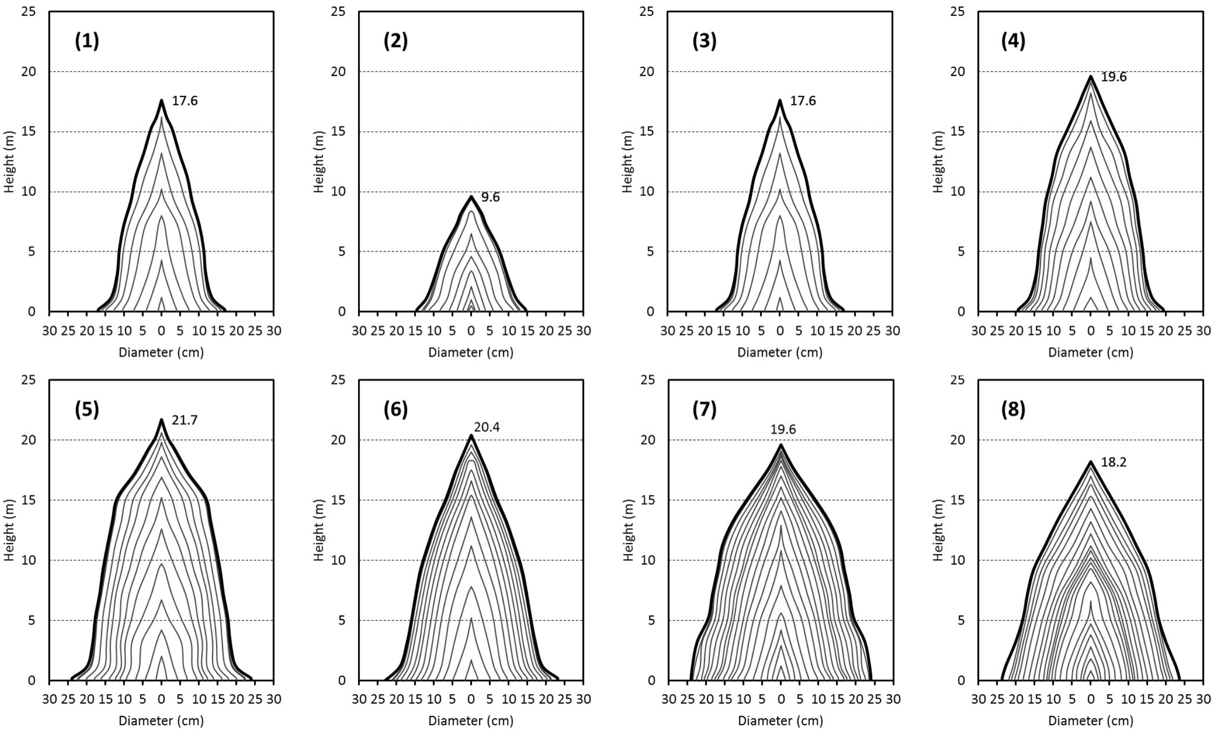

Fig. 2. Diagram of stem analysis for the 8 sample trees.

Materials and Methods

Study area

In 2012 a total of 8 permanent monitoring plots with radius of 11.3 m was installed over red pine stands in Gangneung, Jeongseon, Samcheok and Yangyang in the national forests of Eastern Region in Korea (Fig. 1).

The study plots were selected based on following specifications; at least 10 years in age, unthinned for recent years, free of identifiable defects from disease or insect attack, not heavily damaged by snow or wind storms (Eastern Regional Office of the Korea Forest Service 2012). The summary of the 8 permanent plots in Table 2 shows that the slope gradient ranges in 16∼37°, slope aspect in 170∼

316°, stand density in 425∼1,675 trees/ha, mean DBH in 15.0∼34.2 cm, mean height in 9.0∼18.4 m, mean volume in 0.089∼0.695 m^3/tree, stand volume in 132∼380 m^3/ha and site index in 12∼18.

Data collection and analysis

Eight dominant trees which were standard single-stemmed, free of detectable damage, and showing no obvious suppression were felled and stem-sectioned to collect stem profile data. Each tree was stem-sectioned at 20 cm and 1.2 m above the stump and thereafter at 2 m interval until the small top diameter <6 cm. Two diameters outside bark (dob) and two diameters inside bark (dib) perpendicular to each other were measured and averaged to obtain dob and dib measurements (Eastern Regional Office of the Korea Forest Service 2012). The volume of each section from the stump to the small top diameter was computed using Smalian's formula (Lee 1995). The portion from the last cut to the tip of the tree was calculated by the volume of a cone.

These section volumes were then summed to obtain total tree volume (both inside and outside bark) and compared to the ones by Korea Forest Research Institute (KFRI 2012b). The bark thickness and bark volume were calculated from stem profile data according to the relative diameters of sample trees which were obtained by dividing section diameter by stump diameter.

Total increments of diameter at breast height (dbh), height and volume were measured and periodic annual increments (PAI) for 5 years were computed. Also growth percentages were obtained using Pressler's formula (Lee 1995).

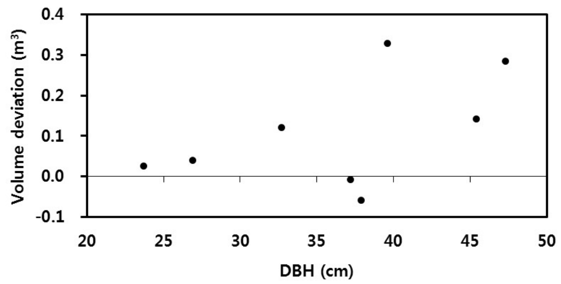

Fig. 3. Tree volume deviation between our study and KFRI (2012b).

Results and Discussion

Characteristics of sample trees

The ages of the trees ranged in 34∼99 years, diameter at breast height (dbh) in 23.7∼47.3 cm, height in 9.6∼21.7

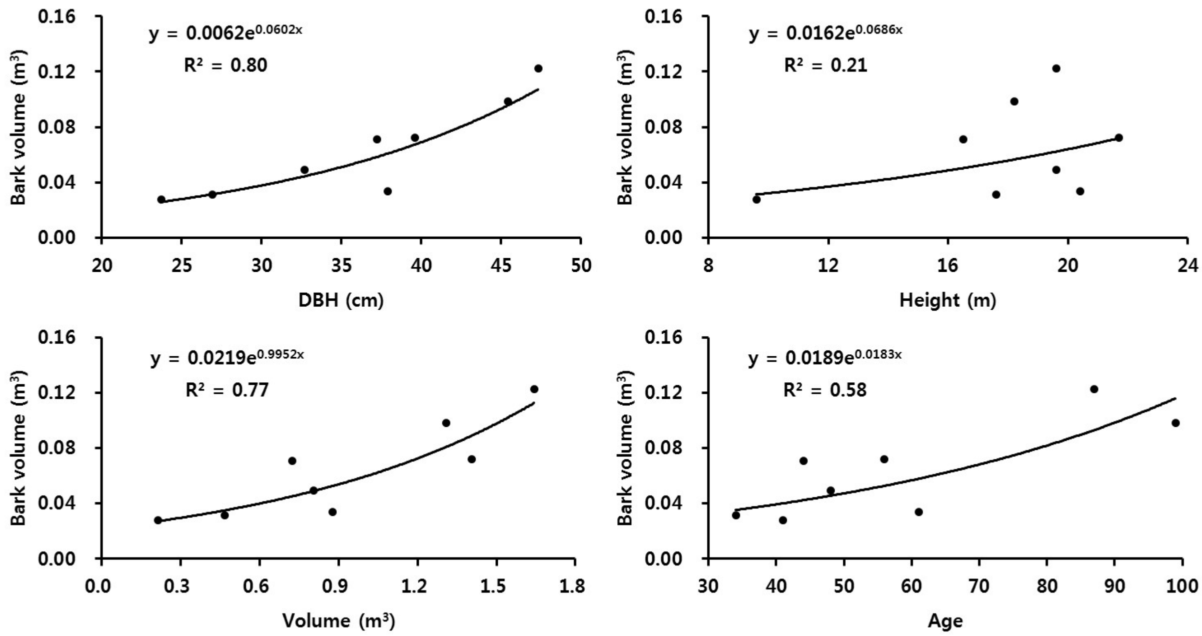

Fig. 4. Relationship of total bark volume with DBH, height, volume and age.

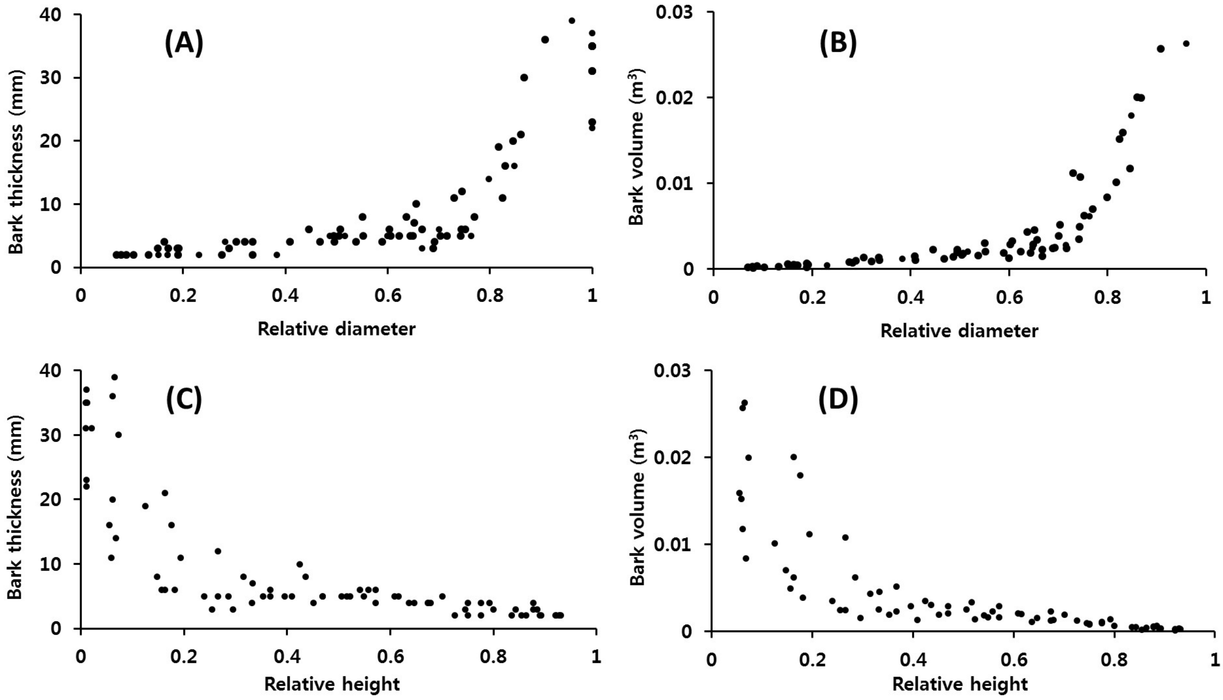

Fig. 5. Relationship of bark thickness and volume by relative diameter and height.

m, stem volume in 0.2120∼1.6424 m^3 and form factor in 0.38∼0.53 (Table 2).

Diagrams of stem analysis show the growth patterns of diameter and height for the 8 sample trees. The diameter and height growth patterns are different in each sample tree with varying form factors (Fig. 2).

When the tree volume deviations were analyzed by subtracting stem volume of KFRI (2012b) from the one of our study, there was difference at 10% significance level ($p=0.06$), because the volumes were highly different in dbh >40 cm dbh compared to dbh <40 cm (Fig. 3).

After removing 3 data with dbh >40 cm, there was no significant difference ($p=0.47$) in the volumes between our study and KFRI's study (2012), showing the similar trend to the study on Korean pine by Seo et al. (2014).

Bark thickness and stem volume

Total bark volume was examined in terms of dbh, height, volume and age. The result showed that the bark volume tended to increase with all those factors and especially the coefficients of determinant of dbh and volume were relatively high of 0.80 and 0.77 respectively (Fig. 4). This result is agreed with the result of the study by Son et al. (1998) in which the bark volume increased with the stem volume.

The bark thickness and bark volume increased with increasing relative diameters (Fig. 5A, B) and bark volume decreased with increasing relative heights (Fig. 5C, D).

DBH, height and volume growth

The total dbh growth of 8 trees had increasing pattern as the trees aged. The average dbh (bold line) approached 11.9 cm (age 20), 25.1 cm (age 40), 32.6 cm (age 60), 37.8 cm (age 80) and 40.3 cm (age 95), respectively (Fig. 6A). Compared at base age 40, the highest DBH growth was founded in Site 6 (Dongmak-ri, Geundeok- myeon, Samcheok-si), followed by Site 4 (Bancheon-ri, Imgye-myeon, Jeongseon-gun) and Site 5 (Jigwon-ri, Imgye-myeon, Jeongseon-gun).

The periodic annual increments (PAI) of dbh increased at early ages and then tended to decrease gradually. The PAIs of 8 trees had different peaks which fluctuated at the same age (Fig. 6B). There existed one PAI which was much higher than other PAIs at age 30∼40. This can be

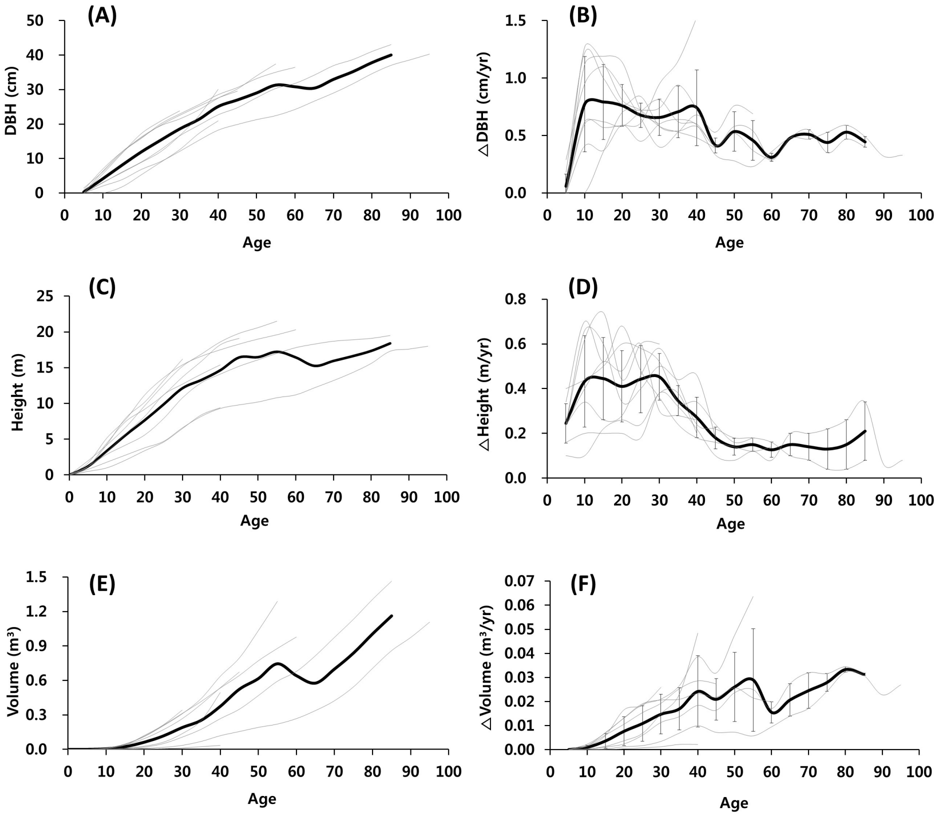

Fig. 6. Total growth and periodic annual increment (PAI) for DBH, height and volume.

explained at Fig. 2～3, where most sample trees have a high dbh growth at early age but the trees of site 3 (Hama-eup-ri, Nogok-myeon, Samcheok-si) have a relatively low growth of dbh at early age and a high growth thereafter. The standard deviation of PAI was relatively high of 0.18～0.42 cm between age 10～20 compared to other ages. The average PAI was the highest at age 15 (0.8 cm/yr).

The height growth pattern showed the similar to dbh growth. As shown in Fig. 6C, the height approached 7.7 m (age 20), 14.6 m (age 40), 16.4 m (age 60), 17.4 m (age 80) and 18.0 m (age 95). The highest growth of height was founded in Site 5, site 4 and 6 in order. The standard deviation of PAI was relatively high of 0.16～0.20 cm between age 10～20 compared to other ages. The average PAI of height was the highest (0.45 m/yr) at age 30 (Fig. 6D).

The volume curve showed that the total volume reached 0.0621 m^3 (age 20), 0.3745 m^3 (age 40), 0.6415 m^3 (age 60), 1.0054 m^3 (age 80) and 1.1081 m^3 (age 95). The highest volume growth was founded in Site 5, followed by Site 4 and 6 (Fig. 6E). The average standard deviations of PAI were relatively high of 0.0144～0.0213m^3 between age 50～55 (Fig. 6F) and the PAI continued to increase up to age 80.

Growth percentage

The growth percentages of dbh, height and volume using Pressler's formula were calculated. The growth percentages of diameter, height and volume decreased with age, especially dbh and height growth percentages felled down rapidly until age 30 and volume growth percentage felled down rapidly at age 45 (Table 3). The percentage of dbh growth decreased to 9.0% (age 20), 3.2% (age 40), 1.1% (age 60), 1.5% (age 80) and 0.8% (age 95). The percentage of height growth showed the similar pattern to diameter. The percentage of volume growth decreased to 19.6% (age 20), 8.4% (age 40), 2.9% (age 60), 4.0% (age 80) and 2.6% (age 95). Volume growth percentage was much higher than dbh and height growth percentages, which was the similar result to the study on Korean pine by Seo et al. (2014). Meanwhile the percentage of volume growth in our study was higher than the percentages by KFRI (2012b).

Table 3. Growth percentage of DBH, height and volume by age

Age	Growth percentage (%)			
	DBH	Height	Volume	
			Our study	KFRI (2012b)
10	27.9	18.0	32.9	
15	12.5	10.1	25.2	11.33
20	9.0	6.4	19.6	7.53
25	5.5	5.2	14.0	5.46
30	4.4	4.6	11.8	4.15
35	3.9	3.1	10.1	3.25
40	3.2	2.0	8.4	2.61
45	1.6	1.1	4.7	2.12
50	1.9	0.9	4.7	1.76
55	1.5	0.9	3.9	1.47
60	1.1	0.8	2.9	1.23
65	1.4	1.1	4.1	1.03
70	1.6	1.0	4.0	0.88
75	1.3	0.9	4.0	0.75
80	1.5	1.0	4.0	0.64
85	1.2	1.2	3.1	
90	0.8	0.3	2.5	
95	0.8	0.4	2.6	

Conclusion

The study was carried out to analyze the growth of *Pinus densiflora* by stem analysis in the Eastern Region of Korea. A total of 8 dominant trees selected from each of 8 site were stemmed and used for the analysis. Total growth of diameter at breast height (dbh), height and stem volume were measured and periodic annual increments (PAI) and growth percentage were computed. Also bark volumes and percentages with dbh, height, volume and age and bark thickness, volume and percentage with relative dbh and height were calculated.

As the main results from the stem profile data of 8 trees, the age ranged in 34~99 years, dbh in 23.7~47.3 cm, height in 9.6~21.7 m, stem volume in 0.2120~1.6693 m^3. Stemmed volumes by our study and Korea Forest Research Institute (2012b) were statistically different ($p=0.06$). But there was no difference when the data over dbh 40 cm were eliminated.

The bark volume had a relatively strong trend to increase with dbh ($R^2=0.80$) and volume ($R^2=0.78$) than with height ($R^2=0.58$) and age ($R^2=0.20$).The bark thickness and volume increased with relative dbh but decreased with relative height.

The average PAI of dbh and height reached the highest at 0.8 cm/yr (age 15) and at 0.45 m/yr (age 30) respectively, while the average PAI of volume steadily tended to increase up to age 80. The growth percentages of dbh, height and volume tended to decrease with age and volume growth percentage was much higher than the one by KFRI (2012b) and the growth percentage of dbh and height.

The results of our study will provide basic data to growth and yield studies of the future and it is thought that a long-term monitoring of major planting tree species is required to accumulate more experimental data for the studies.

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