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Comparison of Growth and Allometric Change of Stand and Dominant Trees in *Pinus koraiensis* Plantation over 34 Years

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Abstract

This study was conducted to find out the growth pattern of *Pinus koraiensis* plantation over 34 years, focusing on DBH, height, basal area and allometric change. Total increment (TI), mean annual increment (MAI) and correlation coefficient were calculated and compared with stand and dominants. Total increment and mean annual increment of both DBH and height of dominants were bigger than those of stand. The difference was apparently shown bigger in DBH than height. Unlike DBH and height the total increment and mean annual increment of basal area per hectare of dominants were distinctively smaller than those of stand. Furthermore MAI of dominant was increasing until age 42, while MAI of stand increased at early ages and then gradually decreased after culmination like MAIs of DBH and height. MAIs of basal area of dead trees at each measurement tended to increase until early age (18 years in this study), while it reached a peak and gradually decrease after that (21 years in this study). Correlation coefficient between DBH and height tended to decrease as both dominant and stand age and the difference between dominant and stand was not clearly shown over the measurement period. Correlation coefficients between DBH and crown width tended to decrease as the trees age and correlation coefficients of dominant were clearly shown smaller than that of stand. Correlation coefficients of height and crown width also was found to be similar to correlation coefficients between DBH and crown. Meanwhile correlation coefficient of height and crown width dropped more radically than coefficient of DBH and crown width as the trees age.

Key Words: dominant, growth pattern, mean annual increment, stand, total increment

Introduction

A diameter at breast height (DBH) and height are the important factors in the forest resource inventory and are an essential component in interpreting the stem volume, growth and stand structure of the trees (Curtis 1967; Moore et al. 1996; Peng et al. 2001; Avery and Burkhart 2002; Shama et al. 2002). The minimum data measurements should include dbh, height and crown measures and satisfaction of growth models depends on the availability of high-quality data (Burkhart 2008). Also a stand basal area is a key component of stand level, since it is directly converted to other economically important variables, such as total stand volume and quadratic mean diameter (Woollons and Hay-

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ward 1985; Hein and Dhôte 2006; Castedo-Dorado et al. 2007).

Accurate forecast of growth and yield can make foresters crucial forest management decision and purpose of growth and yield model can be regarded as to capture the essential elements of stand or tree dynamics in a relatively small set of mathematical equations (Amateis et al. 1996; Scolforo et al. 2017). That is, growth and yield models are used to determine how much stand or tree characteristics such as DBH, height and basal area at one point in time will have change at a future time (Clutter 1963; Borders et al. 1984). Such an understanding is crucial to forest managers because it helps them make forest management decisions. Effective decision making for forest management may depend on reliable forecasts of the growth and yield.

Long-term observation is very important for understanding forest dynamics and mechanisms. Data resulting from periodically repeated measurement of permanent sample plots is preferred and referred to as a real growth series data (Lee 2000; Takahashi et al. 2003; Seo et al. 2014). Using these long term data many studies have been conducted for wood harvesting and investments as well as stand dynamics and modeling growth (Bernard 1995; Thomas 1996; Lee et al. 2000; Mäkinen and Isomäki 2004; Amateis and Burkhart 2005; Sánchez-González et al. 2005; King et al. 2006; Chikumbo and Steward 2007; Burkhart 2008)

Meanwhile, Korean white pine (*Pinus koraiensis*), a representative economic species of Korea, has been planted with 440,000 hectares since the 1960s. Currently, the pine forests account for about 18.9% of conifer forests and are the third largest of the planted trees (Korea Forest Service 2016). The pine forests have the usefulness of seed production as well as wood production such as pulp and sawn timber (Korea Forest Research Institute 2012).

As the utilization is expected to increase in the future, more attention will be paid on how to manage the pine trees through long term monitoring. The objectives of this study were 1) to find out the growth pattern of DBH, height and basal area and 2) to compare the allometric change among DBH, height and crown width of *Pinus koraiensis* plantation over 34 years.

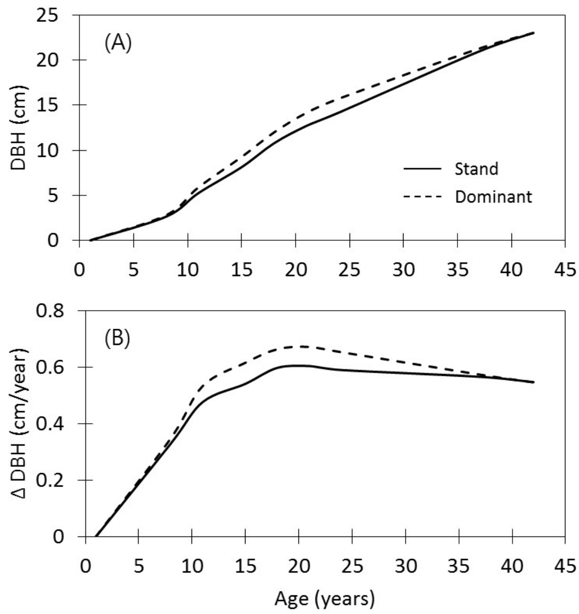

Fig. 1. Comparison of total and mean DBH increment of dominants and stand. (A) Total DBH increment; (B) Mean DBH increment.

Materials and Methods

Study area

The study area is located in the experimental forests of Kangwon National University, Chuncheon-si, Gangwon province. The climate of the site is temperate continental and is hot and humid in summer and low temperature in winter (Choi et al. 2014). The average annual temperature and precipitation are 11.1 °C and 1,347.3 mm respectively (Korea Meteorological Administration 2011). Soil is formed of loam and sandy loam, rich in organic matter and suitable for plant growth (Choi 2003).

Table 1. Stand characteristics of study area

Plot no	Age*(years)	Aspect	Altitude(m)	Slope(°)	Topography	Site index
1	40	NE	500	15.3	Hillside	16
2	44	NE	600	16.2	Hillside	16
Average	42	NE	550	15.7	Hillside	16

* Plantation age

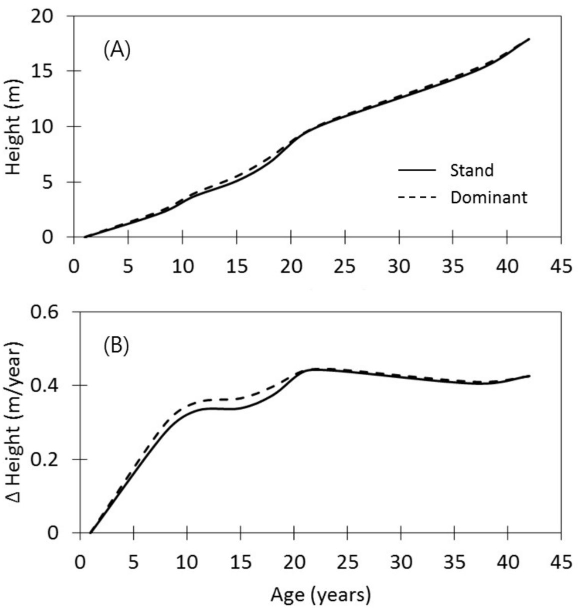

Fig. 2. Comparison of total and mean height increment of domiT-nant and stand. (A) Total height increment; (B) Mean height increment.

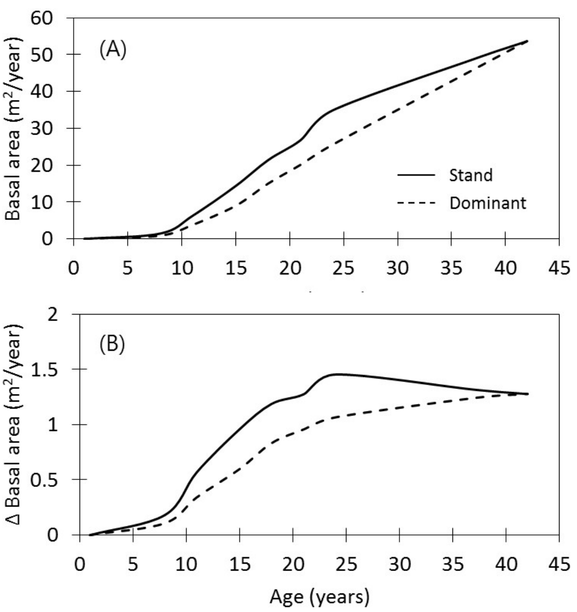

Fig. 3. Comparison of total and mean basal area increment of dominant and stand. (A) Total basal area increment; (B) Mean basal area increment.

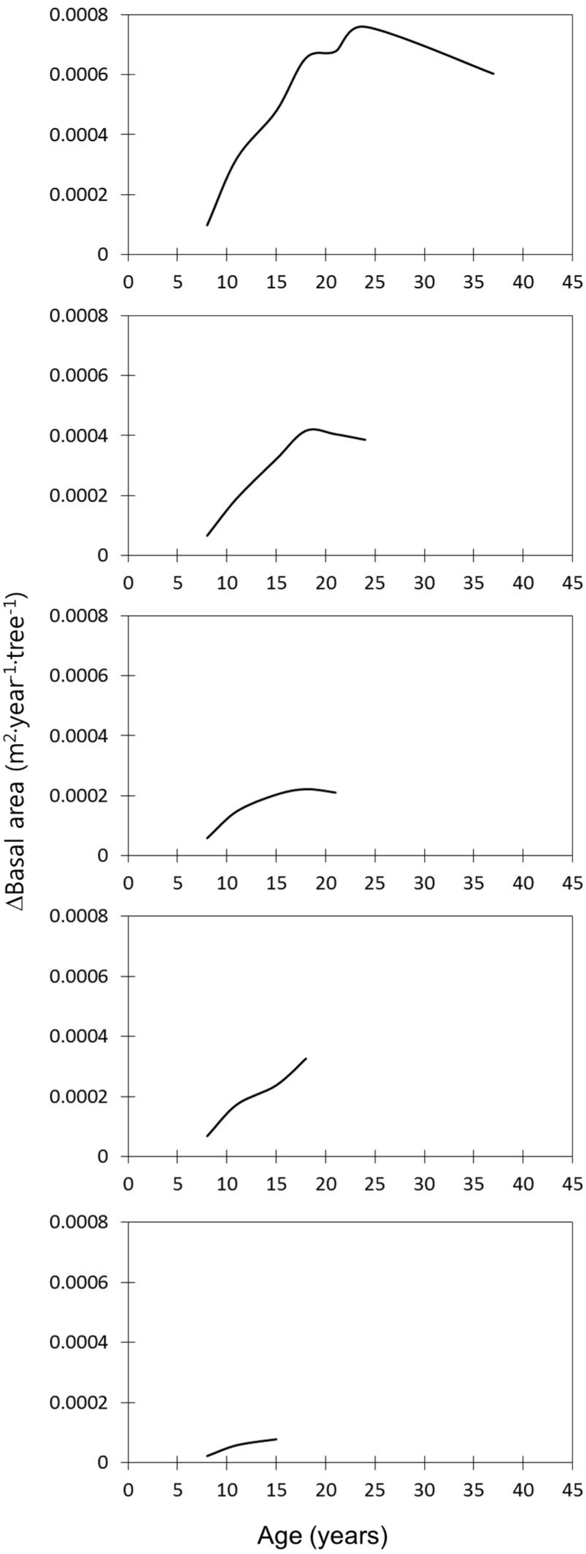

Fig. 4. Mean basal area increment of dead trees before dead.

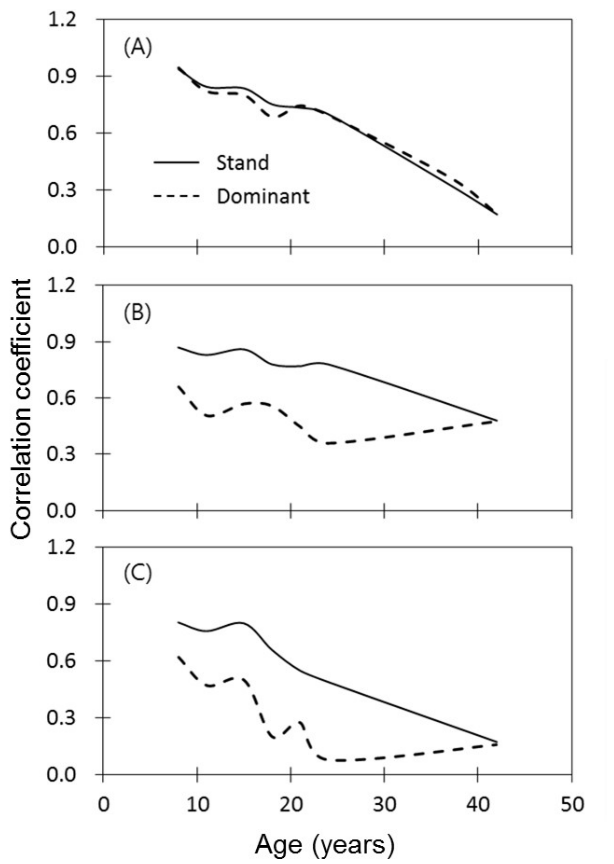

Fig. 5. Relationship of DBH, height, and crown width. (A) DBH vs. Height; (B) DBH vs. Crown width; (C) Height vs. Crown width.

Data collection

Two permanent plots for monitoring on growth of *Pinus koraiensis* were installed with 50m×50m in 1981; one was planted in 1972 and the other in 1976 with about 3000 trees/ha. Site characteristics of the two plots are very homogeneous; aspect is southwest, slope gradient 21 °, altitude 550m, and site index 14 on average (Table 1).

Eight measurements had been made since installation of the plots; 1981, 1984, 1987, 1991, 1994, 1997, 2010, 2015. The plots has not been thinned except lightly thinned about 10% based on basal area in 1991. All trees bigger than 6 cm diameter at breast height (DBH) in each sample plot were labelled with a number and measured for x-y coordinates, height, DBH and crown width with recording dead trees during the successive censuses. DBH was measured to the nearest 0.1 cm with D-tape and total height was measured to the nearest 0.1 m with a digital hypsometer. Crown width was measured based on the four lengths (NSWE) from the base of a trunk to the edge of the crown and calculated averaging them. Only live trees were included in the analysis on DBH, height, basal area and crown width.

Analysis method

Trees were classified into two type; stand which were alive in each year of measurement and dominant trees which were alive until the year of final measurement. Total increment (TI) and mean annual increment (MAI) of DBH, height and basal area were calculated and compared between stand and dominants during inventory years. Also, allometric changes among DBH, height and crown width over 34 years were compared using correlation coefficient. Program EXCEL was used for data processing and graphics.

Results and Discussion

DBH increment

The total increment (TI) of DBH of dominant and stand had an increasing pattern with age, while mean annual increment (MAI) increased at early ages and then slowly decreased with age. This growth pattern was shown in the studies of Seo et al. (2014, 2018) which provided growth patterns of DBH, height and volume of *Pinus densiflora*, *Pinus koraiensis*, and *Larix kaempferi* using stem analysis. TI and MAI of DBH of dominants were apparently bigger than those of stand as shown in Fig. 1. TIs of dominants and stand increased separately to 2.78 cm and 2.63 cm at age 8, 9.26cm and 8.12 cm at age 15, 15.72 cm and 14.17 cm at age 24, 21.29 cm and 20.95 cm at age 37, and 23.01 cm at age 42. MAI of dominants and stand were culminated to 0.67 cm 0.60 cm respectively at age 21 and gradually decreased to 0.52 cm at age 42.

Height increment

Like DBH increment the total height increment normally presented a concave curve (Liao et al. 2003; Kwak et al. 2004; Zuidema et al. 2011; Seo et al. 2014, 2018). TI of height of dominant and stand had an increasing pattern with age, while mean annual increment (MAI) increased at early ages and then gradually decreased after culmination.

TI and MAI of height of dominants were bigger than those of stand, but the difference was found to be less than DBH as shown in Fig. 2. TIs of dominants and stand increase to 2.4 m and 2.2 m at age 8, 5.5 m and 5.1 m at age 15, 10.7 m and 10.6 m at age 24, 15.2 m and 15.0 m at age 37, and 17.9 m at age 42. MAI of dominants and stand were culminated to 0.45 m and 0.44 m respectively at age 24 and gradually decreased to 0.42 m at age 42.

Basal area increment

Unlike DBH and height increment the total increment and mean annual increment of basal area of dominants were distinctively smaller than those of stand as shown in Fig. 3. Furthermore MAI of dominant was increasing until age 42, while MAI of stand increased at early ages and then gradually decreased after culmination like MAIs of DBH and height. Therefore the basal area growth in our study is inferred to be still vigorous to reach the peak and this was consistent with the results from other studies on stem volume growth (Sawata et al. 2007; Pretzsch et al. 2002; Castagneri et al. 2013).

TIs of dominants and stand increased to 0.85 m2/ha and 1.45 m^2/ha at age 8, 8.95 m^2/ha and 14.38 m^2/ha at age 15, 25.57 m^2/ha and 34.93 m^2/ha at age 24, 45.90 m^2/ha and 48.75 m^2/ha at age 37, and 53.67 m^2/ha at age 42. MAI of stand was culminated to 1.46 m^2/ha at age 24 and gradually decreased to 1.28 m^2/ha at age 42. However MAI of dominants were not found to be culminated until age 42; it increased to 0.18 m^2/ha at age 8, 0.59 m^2/ha at age 15, 1.07 m^2/ha at age 24, 1.24 m^2/ha at age 37, and 1.27 m^2/ha at age 42.

MAIs of basal area of dead trees at each measurement were calculated until the age before dead and compared with another during all measurements. As shown in Fig. 4, MAI of dead trees tended to increase until early age (18 years in this study), while it tended to reach the peak and gradually decrease after that (21 years in this study). It is inferred that dead trees can be expected using MAI of basal area and further study is needed.

Allometric change of DBH, height and crown width

Correlation coefficients were calculated between DBH and height, DBH and crown width, and height and crown width to compare the allometric change as stand ages. As shown in Fig. 5, correlation coefficient between DBH and height tended to decrease as both dominants and stand age. Normally DBH and height are highly and positively correlated, but the relationship tended to decrease prominently as the stand ages; in our study it decreased from 0.94 at age 8 to 0.70 at age 24 to 0.18 at age 42. Difference between the two trees was not clearly shown over the measurement period.

Like relationship between DBH and height, correlation coefficients between DBH and crown width tended to decrease as the trees age. Correlation coefficients of dominant were smaller than that of stand and the difference between dominant and stand was clearly shown. Correlation coefficients of height and crown width also showed the same tendency as correlation coefficients between DBH and crown; it tended to decrease as the trees age and correlation coefficients of dominant were apparently smaller than that of stand. Meanwhile correlation coefficient of height and crown width dropped more radically than coefficient of DBH and crown width as the trees age.

Conclusion

This study was conducted to find out the growth pattern of DBH, height and basal area and to compare the allometric change among DBH, height and crown width of *Pinus koraiensis* plantation over 34 years. Trees were classified into stand trees which were alive in each year of measurement and dominant trees which were alive until the year of final measurement. Total increment (TI) and mean annual increment (MAI) of DBH, height and basal area were calculated and compared between stand and dominants during inventory years. Also allometric changes among DBH, height and crown width over 34 years were compared using correlation coefficient.

Total increment of DBH and height of dominant and stand had an increasing pattern with age, while MAI increased at early ages and then slowly decreased with age. Total increment and mean annual increment of DBH of dominants were apparently bigger than those of stand and the difference was shown to be larger than DBH. Unlike DBH and height increment the total increment and mean annual increment of basal area of dominants were distinctively smaller than those of stand. Furthermore MAI of dominant was increasing until age 42, while MAI of stand increased at early ages and then gradually decreased after culmination like MAIs of DBH and height. Therefore the basal area growth in our study is inferred to be still vigorous to reach the rotation age.

MAIs of basal area of dead trees at each measurement tended to increase until early age (18 years in this study), while it tended to reach the peak and gradually decrease after that (21 years in this study). It is inferred that dead trees can be expected using MAI of basal area and further study is needed. Correlation coefficient between DBH and height tended to decrease as both dominant and stand age. Difference between dominant and stand was not clearly shown over the measurement period. Correlation coefficients between DBH and crown width tended to decrease as the trees age and correlation coefficients of dominant were clearly shown to be smaller than that of stand. Correlation coefficients of height and crown width also was found to be similar to correlation coefficients between DBH and crown. Meanwhile correlation coefficient of height and crown width dropped more radically than coefficient of DBH and crown width as the trees age.

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