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研究資料（Research material）

Effects of fertilization, soil and cultivation on annual ring structures of two sugi (*Cryptomeria japonica* D. Don) clones.

IMAI Yuki [1], MISHIRO Akiyoshi [2], HIRAKAWA Yasuhiko [3]* and MARUYAMA Koohei [1]

Abstract

The annual ring structure of two kinds of sugi (*Cryptomeria japonica* D.Don) plus-tree clones (Higashi-Kanbara-7 and Iwafune-4) was examined. The clones were raised in bottomless 1 ㎥ concrete pots for 10 years under a combination of treatments with and without fertilization, with and without cultivation and with two kinds of soil (quaternary diluvium soil and paleo-volcanic soil). Fertilization decreased the minimum density in both cultivated and non-cultivated trees, and only non cultivation increased ring width and decreased mean density. In the non-fertilized tees, differences were found in annual ring structures between soils having different productivities. However, in the fertilized trees, no differences were found among their annual ring structures because the fertilization effect was different in each soil. In addition, no differences were found in annual ring structures between clones irrespective of fertilization. With regard to the cultivation effects, some changes by fertilization were recognized, but the reason for the changes was not clear. The effects of fertilization on annual ring structure components were recognized as an increase in the ring width (RW) with increase of earlywood ring width (EW) and a decrease in mean density (MD) with decreases in earlywood density (EWD) and minimum density (MinD). It appears that the earlywood cells having thin cell walls were formed by fertilization and the fertilization maintained its effect on RW, EW, MD, EWD, MinD and percentage of latewood (PLW) for at least 3 to 4 years.

Key words : fertilization, quaternary diluvium soil, paleo-volcanic soil, cultivation, sugi tree, annual ring structure

1. Introduction

Fertilizers are applied to accelerate tree growth and to improve the wood quality of planted trees. There are many reports on changes in the quality and anatomy of wood caused by fertilization in the United States and Europe (Zobel et al.,1961; Klem,1968; Murphey et al.,1969; Choong et al.,1970; Erickson & Arima,1974; Bendtsen,1978; Zobel & van Buijtenen,1989; Shupe et al.,1996a; Shupe et al.,1996b), and Japan (Kawana & Kawaguchi,1957; Maruyama,1959; Maruyama & Daimatsu,1965; Kuroyanagi & Ishikawa,1962; Ishikawa & Kuroyanagi,1963; Kano & Nakagawa,1964; Shiokura,1975; Ohta,1981). However, it is not so easy to evaluate the fertilization effect on wood quality because there are various factors of effect on wood properties. Therefore, a study using the samples which were strictly controlled in condition for removing the various influences except for the fertilization was attempted (Murphey et al., 1969). In Japan, Maruyama and Inoue also prepared strictly controlled trials in which there were two different kinds of soils, sugi plus-tree clones and cultivations, and examined the fertilization effects on tree growth and development from 1980 to 1989 (Maruyama and Inoue,1992).

In this study, the effects of these treatments on the annual ring structures in terms of wood quality improvement in planted sugi trees were examined using the same samples of the report by Maruyama and Inoue (1992). The study of annual ring structures is very important to clarify the effects of the correlation between accelerated growth and wood properties by fertilization.

2. Materials and Methods

2.1. Materials

Two-year-old sugi stocks, Higashi-Kanbara-7 clones and Iwafune-4 clones, were planted in 12.5mm thick bottomless concrete pots (1m by 1m by 1m) in the University experimental field in the spring of 1980.

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* Department of Wood Properties, Forestry and Forest Products Research Institute (FFPRI), 1 Matsunosato, Tsukuba, Ibaraki, 305-8687, Japan; e-mail: hirakawa@ffpri.affrc.go.jp
1) Retired (Faculty of Agriculture, Niigata University)
2) Deceased (Faculty of Agriculture, Niigata University)
3) Department of Wood Properties, Forestry and Forest Products Research Institute (FFPRI)

They were prepared experimentally with and without fertilization and cultivation, and with two kinds of soil (quaternary diluvium soil and paleo-volcanic soil) until 1989. Fifty grams of the fertilizer (N 20%, P11%, K 10%) was applied to each tree in the first April and increased by 20 percent in April of each succeeding year. Cultivation was done to a depth of 30 cm by shovel each April.

Although 48 sample trees (16 treatments: with and without fertilization and cultivation, two of soil and two clones, and three replicates) were planted, six trees were removed because two died and four developed double stems during the experiments. The remaining 42 trees were felled in the summer of 1994. Eighteen of these trees, in 4 groups (3 groups of Higashi-kanbara-7 clones and one group of Iwafune-4 clones) were used to examine the effects of treatment on annual ring structure.

The combinations of treatments, height and diameter at breast height of sample trees are shown in Table 1. Discs (5 cm thickness) were taken from breast height of each tree and used for analysis.

2.2 Measurement

The annual ring structures were analyzed on air-dried strips of 2 mm thickness by soft X-ray densitometry which was described in detail in a previous report (Ohta, 1981).

Annual ring structures were analyzed from 1984 to 1993. At breast height wood formation commenced in 1984 and it was reported that the fertilizer effect would continue for a fairly long time (Kano & Nakagawa, 1964) although the treatments were finished in 1989. Measurements were taken for the annual ring width (RW), earlywood width (EW), late wood width (LW), mean density (MD), earlywood density (EWD), latewood density (LWD), maximum density (MaxD), minimum density (MinD) and percentage of latewood (PLW) from pith to bark in north and south directions. The average value of two directions was used for the analytical data. Boundaries between earlywood and latewood were decided by a criterion based on density of 550 ㎏ / m^3.

3. Results and Discussion

3.1 Effects of fertilization on annual ring structure

Table 2 shows the mean values of each component of annual ring structure in four groups with and without fertilization (other treatments were all the same) and the results of their statistical analysis. In each group, mean values of RW, EW, and LW tended to be increased, and MD, EWD, LWD, MaxD, MinD and PLW decreased by fertilization. However, in the group of CQI (with cultivation, quaternary diluvium soil and Iwafune-4 clones), the PLW was slightly increased by fertilization. In the groups of NQH (without cultivation, quaternary diluvium soil and Higashi-kanbara-7 clones) and NVH (without cultivation, paleo-volcanic soil and Higashi-kanbara-7 clones), significant differences were found between with and without fertilization in many components. This means that annual ring structure was significantly changed by fertilization.

As shown in Table 2, in the group of NQH, a significant fertilization effect was found in RW, EW, MD, EWD, MinD and PLW, and in MD, EWD, LWD and MinD in the group of NVH, while in CQH (with cultivation, quaternary diluvium soil and Higashi-kanbara-7 clones) and CQI, a significant fertilization effect was only found in MinD. The reason for little influence may be that the fertilization effect was cancelled by cultivation.

The reason that significant fertilization effect on RW was found only in the group of NQH appears to be that the experiment started in 1980, but the data on annual ring structures could only be obtained from 1984, as described before. Tree growth is not always promoted by fertilization (Ishikawa & Kuroyanagi,1963).

The significant fertilization effect was found in MinD in all groups, but not in LWD and MaxD by fertilization. It seems that MinD is the indicator for gauging the sensitivity of changes in nutritional circumstances such as fertilization. As Ohta (1978) reported that trees grown in polluted areas are characterized by decreases in MaxD and RW, and an increase in MinD, the MinD might be one of the factors that are readily influenced by changes in growing circumstances. It appears that the formation of thin earlywood cell walls influenced the lower MinD through fertilization.

3.2 Effect of soil on annual ring structure

Table 3 shows the mean values of each factor of annual ring structures of Higashi-Kanbara-7 clones in two kinds of soil and the results of their statistical analysis. The results for without fertilization showed that LW was significantly wider, and EWD, LWD, MD, MaxD and MinD were significantly lower in the paleo-volcanic soil than in the quaternary diluvium soil. As it has been reported that the productivity is greater in paleo-volcanic soil than in quaternary diluvium soil (Maruyama & Inoue, 1992), these results indicate a difference in productivity between soils. A Higashi-Kanbara-7 clone grown in paleo-volcanic soil showed the annual ring structure like well grown trees; however, no significant differences were found in RW and EW between soils. At present it is not clear why the significant difference was found between

Table 1. Height (H) and diameter of breast height (DBH) of sample trees

	Ⅰ		Ⅱ		Ⅲ		Mean	
Symbol	H (m)	DBH (cm)	H (m)	DBH (cm)	H (m)	DBH (cm)	H (m)	DBH (cm)
FNQH	6.79	12.6	6.12	11.0	3.55	6.8	5.48	10.1
NNQH	6.70	11.6	2.35	2.6	2.51	5.8	3.85	6.6
FNVH	6.86	14.4	6.45	12.3	-	-	6.65	13.3
NNVH	6.56	10.7	4.67	8.3	-	-	5.61	9.5
FCQH	4.06	8.2	6.18	11.8	-	-	5.12	10.0
NCQH	5.30	6.4	5.28	9.0	-	-	5.29	7.7
FCQI	5.42	8.0	6.32	10.4	-	-	5.87	9.2
NCQI	3.92	5.3	6.21	8.4	-	-	5.09	6.8

Ⅰ, Ⅱ, Ⅲ : Three replicated plots

Table 2. A significant table of factors for ring structure of sample trees with and without fertilization

Components	NNQH	FNQH	NCQH	FCQH	NCQI	FCQI	NNVH	FNVH
RW (mm) 1)	2.78	4.04 *	3.15	3.72 ns	2.47	3.57 ns	3.64	4.80 ns
EW (mm) 2)	2.41	3.62 *	2.74	3.27 ns	2.17	3.20 ns	3.16	3.99 ns
LW (mm) 3)	0.36	0.42 ns	0.40	0.44 ns	0.29	0.39 ns	0.49	0.53 ns
MD (kg/m^3) 4)	367.2	306.6 **	361.5	341.4 ns	336.0	328.0 ns	343.2	301.6 **
EWD (kg/m^3) 5)	299.7	247.7 **	289.5	273.4 ns	279.8	261.1 ns	265.9	237.4 **
LWD (kg/m^3) 6)	731.0	714.4 ns	745.1	723.1 ns	704.3	701.3 ns	765.6	729.4 *
MaxD (kg/m^3) 7)	879.4	860.7 ns	893.7	847.1 ns	814.4	833.1 ns	947.2	903.5 ns
MinD (kg/m^3) 8)	224.1	155.8 **	226.2	176.6 *	198.9	153.2 **	176.6	143.2 **
PLW (%) 9)	15.6	12.1 *	15.7	14.4 ns	12.7	14.8 ns	15.0	12.7 ns

Table 3. A significant table of factors for ring structure of Higashi-Kanbara-7 clone, without cultivation, in the quaternary diluvium soil and paleo-volcanic soil

Components	NNQH	NNVH	FNQH	FNVH
RW (mm) 1)	2.78	3.64 ns	4.04	4.80 ns
EW (mm) 2)	2.41	3.16 ns	3.62	3.99 ns
LW (mm) 3)	0.36	0.49 **	0.42	0.53 *
MD (kg/m^3) 4)	367.2	343.2 *	306.6	301.6 ns
EWD (kg/m^3) 5)	299.7	265.9 **	247.7	237.4 ns
LWD (kg/m^3) 6)	731.0	765.6 *	714.4	729.4 ns
MaxD (kg/m^3) 7)	879.4	947.2 **	860.7	903.5 ns
MinD (kg/m^3) 8)	224.1	176.6 ns	155.8	143.2 ns
PLW (%) 9)	15.6	15.0 ns	12.1	12.7 ns

Table 4. A significant table of factors for ring structure of Iwafune-4 clone and Higashi-Kanbara-7 clone, with cultivation, in quaternary diluvium soil

Components	NCQI	NCQH	FCQI	FCQH
RW (mm) 1)	2.47	3.15 ns	3.57	3.72 ns
EW (mm) 2)	2.17	2.74 ns	3.20	3.27 ns
LW (mm) 3)	0.29	0.40 ns	0.39	0.44 ns
MD (kg/m^3) 4)	336.0	361.5 *	328.0	341.4 ns
EWD (kg/m^3) 5)	279.8	289.5 ns	261.1	273.4 ns
LWD (kg/m^3) 6)	704.3	745.1 ns	701.3	723.1 ns
MaxD (kg/m^3) 7)	814.4	893.7 ns	833.1	847.1 ns
MinD (kg/m^3) 8)	198.9	226.2 ns	153.2	176.6 *
PLW (%) 9)	12.7	15.7 ns	14.8	14.4 ns

Table 5. A significant table of factors for ring structure of Higashi-Kanbara-7 clone, with and without cultivation, in quaternary diluvium soil

Components	NNQH	NCQH	FNQH	FCQH
RW (mm) 1)	2.78	3.15 ns	4.04	3.72 ns
EW (mm) 2)	2.41	2.74 ns	3.62	3.27 ns
LW (mm) 3)	0.36	0.40 ns	0.42	0.44 ns
MD (kg/m^3) 4)	367.2	361.5 ns	306.6	341.4 **
EWD (kg/m^3) 5)	299.7	289.5 ns	247.7	273.4 **
LWD (kg/m^3) 6)	731.0	745.1 ns	714.4	723.1 ns
MaxD (kg/m^3) 7)	879.4	893.7 ns	860.7	847.1 ns
MinD (kg/m^3) 8)	224.1	226.2 ns	155.8	176.6 *
PLW (%) 9))	15.6	15.7 ns	12.1	14.4 ns

Symbol : F and N in the first part mean with and without fertilization respectively, and C and N in the second mean with and without cultivation, and Q and V in the third mean quaternary diluvium soil and paleo-volcanic soil, and H and I in the fourth mean Higashi-Kanbara-7 clone and Iwafune-4 clone respectively.

Legend :

FNQH; With fertilization, without cultivation, quaternary diluvium soil and Higashi-Kanbara-7 clone
NNQH; Without fertilization, without cultivation, quaternary diluvium soil and Higashi-Kanbara-7 clone
FNVH; With fertilization, without cultivation, paleo-volcanic soil and Higashi-Kanbara-7 clone
NNVH; Without fertilization, without cultivation, paleo-volcanic soil and Higashi-Kanbara-7 clone
FCQH; With fertilization, with cultivation, quaternary diluvium soil and Higashi-Kanbara-7 clone
NCQH; Without fertilization, with cultivation, quaternary diluvium soil and Higashi-Kanbara-7 clone
FCQI; With fertilization, with cultivation, quaternary diluvium soil and Iwafune-4 clone
NCQI; Without fertilization, with cultivation, quaternary diluvium soil and Iwafune-4 clone

1) Annual ring width, 2) Earlywood width, 3) Latewood width, 4) Mean density, 5) Earlywood density, 6) Latewood density, 7) Maximum density, 8) Minimum density, 9) Percentage of latewood

＊; significant at the 5 % level, ＊＊; significant at the 1 % level, ns; not significant these components.

In the fertilized trees, LW in the paleo-volcanic soil was 1.3 times wider than in quaternary diluvium soil. However, no significant differences were found in components. It appears that the fertilization effect is greater in quaternary diluvium soil than paleo-volcanic soil (Maruyama & Inoue, 1992). It is noteworthy that there were no notable differences in annual ring structures of the Higashi-Kanbara-7 clones grown in the two soils with fertilization

3.3 Effect of clone on growth ring structure

Table 4 shows the mean values of each component of growth ring structures in the two clones and the results of their statistical analysis. In the non-fertilized trees, a significant difference between the Iwafune-4 clone and the Higashi-Kanbara-7 clone was found only in MD in quaternary diluvium soil with cultivation. The Higashi-Kanbara-7 clone had slightly wider RW and higher MD than the Iwafune-4 clone. There seems to be a relationship between higher PLW and EWD, though not significant. In the non-fertilized group, RW, EW, LW, and PLW in the Higashi-Kabara-7 clones were 1.2 to 1.3 times larger than in the Iwafune-4 clones.

In the fertilized groups, significant differences were found only in MinD between two clones in quaternary diluvium soil with cultivation. The difference between the two clones was smaller in many components with fertilization than without fertilization.

3.4 Effect of soil cultivation on annual ring structure

Table 5 shows the mean values of each component of annual ring structure in the Higashi-Kanbara-7 clone with and without cultivation, and the results of their statistical analysis. In the non-fertilized trees, there was no effect of cultivation whatsoever on the annual ring structures. However, in the fertilized trees, MD, EWD and MinD tended to be significantly increased by cultivation. It appears that RW and EW were narrower, and LW with cultivation was wider than without cultivation, though not significantly. At present, the reason why MD, EWD and MinD were increased by cultivation is not clear.

3.5 Variations of annual ring components from 1984 to 1993

Next, using 6 sample trees consisting of 3 NNQH trees (Higashi-Kanbara-7 clones without fertilization, without cultivation, quaternary diluvium soil) and 3 FNQH trees (Higashi-Kanbara-7 clones with fertilization, without cultivation, quaternary diluvium soil) respectively, the annual ring structure variations were examined in detail.

Fig. 1 shows the variations of RW with and without fertilization from 1984 to 1993. The values of RW decreased from 1984 to 1988 with increase of age, irrespective of fertilization and thereafter remained more or less constant. The treatment ended in 1989, but it appears that the fertilization effect continued for some years after the stoppage of fertilization although two samples values were nearly the same in 1991and 1992.

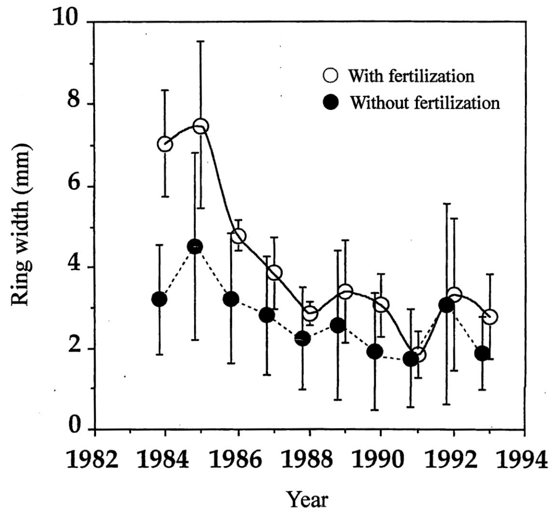

Fig. 1. Variation of annual ring width (RW) of sugi with and without fertilization from 1984 to 1993.
Error bars; standard deviation

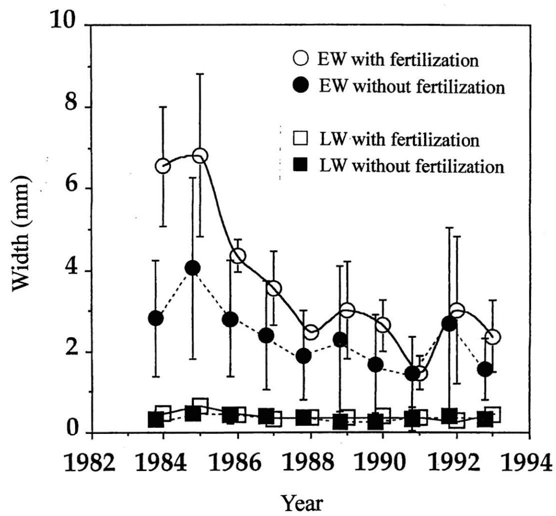

Fig. 2. Variation of earlywood (EW) and latewood widths (LW) of sugi with and without fertilization from 1984 to 1993.
Error bars; standard deviation

Fig. 2 shows the variations of EW and LW with and without fertilization from 1984 to 1993. The variation pattern in EW is almost the same as RW. The LW was almost constant at 0.3 to 0.5 mm irrespective of fertilization and aging. The RW with fertilization was wider than without fertilization, but LW was almost the

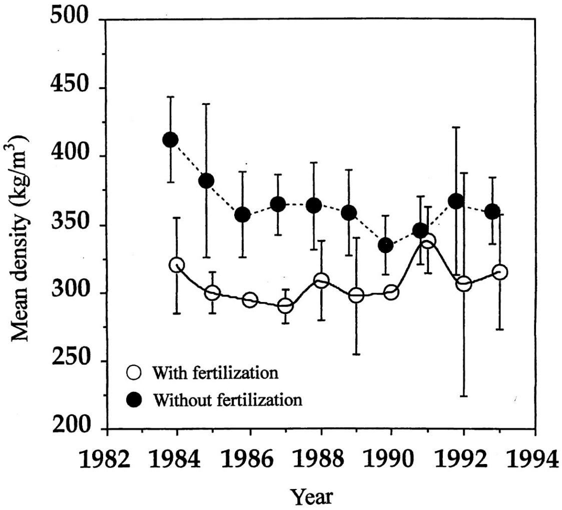

Fig. 3. Variation of mean density (MD) of sugi with and without fertilization from 1984 to 1993.
Error bars; standard deviation

same.

Fig. 3 shows MD with and without fertilization from 1984 to 1993. The MD was higher in non-fertilized than in fertilized trees. The MD without fertilization was almost constant after 1986, but slightly high in fertilized trees.

Figs. 4 and 5 show the variation of LWD and EWD, MaxD and MinD with and without fertilization from 1984 to 1993. The LWD and MaxD were almost constant, approximately 750 and 850 kg/m^3, respectively, regardless of fertilization and aging (MaxD with fertilization showed slightly higher values in 1984, 1985 and 1993). However, EWD and MinD were always higher in non-fertilized than in fertilized trees and their variation patterns from 1984 to 1993 were almost the same.

The reason why EWD and MinD with fertilization

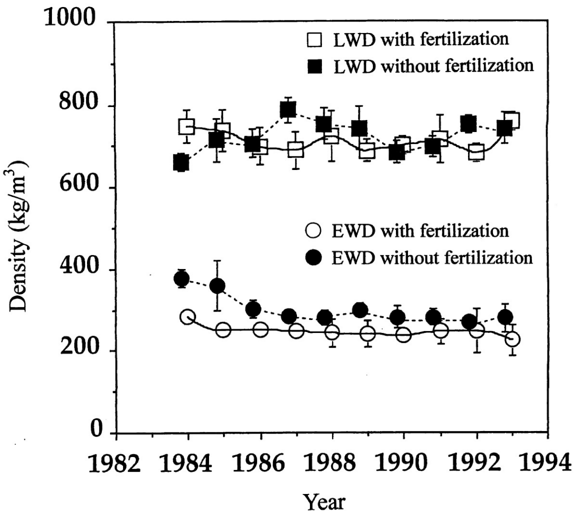

Fig. 4. Variation of latewood density (LWD) and earlywood density (EWD) of sugi with and without fertilization from 1984 to 1993.
Error bars; standard deviation

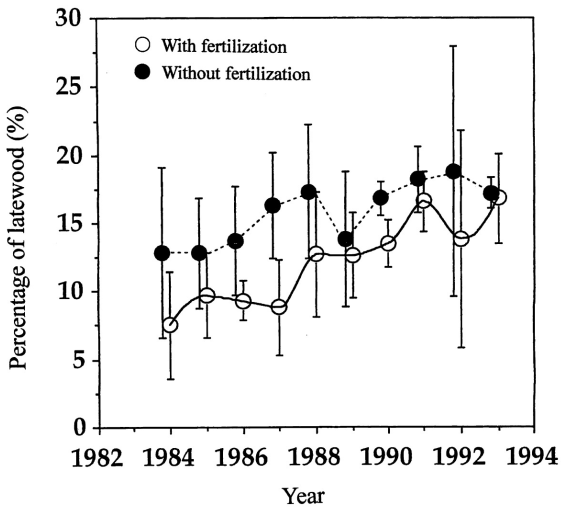

Fig. 5. Variation of maximum density (MaxD) and minimum density (MinD) of sugi with and without fertilization from 1984 to 1993.
Error bars; standard deviation

were less than without fertilization is that earlywood cells with thinner cell walls were formed when the diameter growth was promoted by fertilization. Fujisawa et al. (1993) also reported that the variation patterns in LWD and MaxD, and EWD and MinD respectively, were very similar in sugi without fertilization.

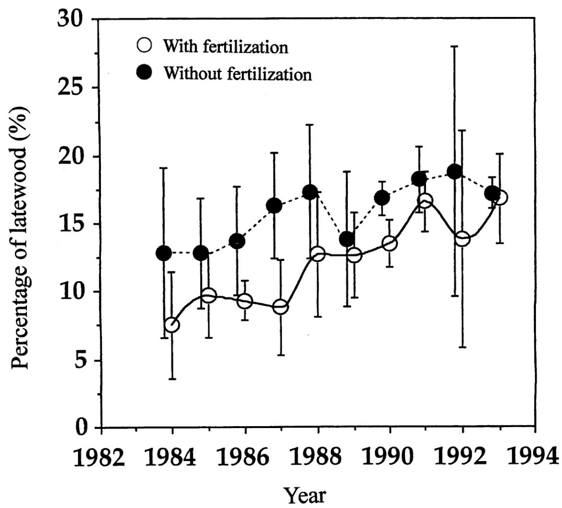

Fig. 6. Variation of percentage of latewood (PLW) of sugi with and without fertilization from 1984 to 1993.

Fig. 6 shows the variation of PLW with and without fertilization from 1984 to 1993. The PLW increased slightly with increase of age in both treatments, but it was always higher without fertilization than with fertilization. The RW was narrow in non-fertilized trees, but LW was almost the same. As shown in Figs. 1, 2 and 6, RW tended to decrease from the pith toward the bark, while LW remained more or less constant and PLW increased with aging. Fujisawa et al. (1993) reported that in sugi without fertilization, PLW decreased outwards from pith for a number of rings but thereafter became constant.

Further, a continuation of the fertilization effect was found on MD (Fig. 3), EWD (Fig. 4), MinD (Fig. 5) and PLW (Fig. 6) for at least 3 to 4 years after fertilization ended.

3.6 Mutuality of annual ring components

3.6.1 Relations of annual ring width to earlywood width and latewood width

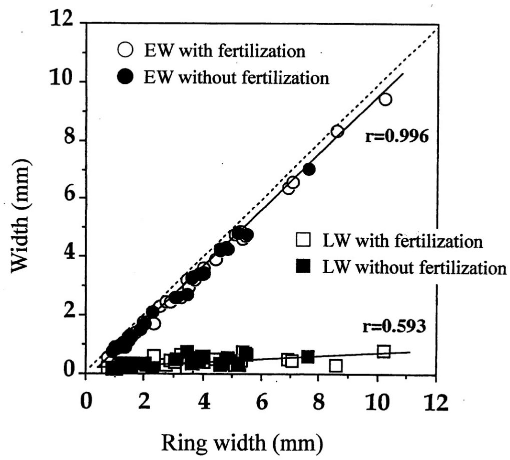

Fig. 7. Relationship between annual ring width (RW), earlywood width (EW) and latewood width (LW).

Fig. 7 shows that high positive correlations were found between RW, and EW and LW, respectively. Although both EW and LW increased linearly with increase in annual ring width, the increase in latewood was very small. The increase in RW depended almost entirely on the increase in earlywood (The 45-degree line shows the RW). This relation was completely unaffected by fertilization. Similar results were reported by Kuroyanagi & Ishikawa (1962).

3.6.2 Relation of ring width to mean density

There are many reports on the relation between growth rate and density, and many of them indicated that there was a negative correlation. Fig. 8 shows the relation between RW and MD. The MD was lowered by fertilization and tended to decrease slightly with increase of RW regardless of fertilization, although the correlation coefficient was loose. When RW was increased by fertilization and consequently reduced the values of PLW and MD, EW was considerably wide but there was no change in LW.

Most MD values without fertilization were above 310 kg/m^3. The basic density of sugi is usually approximately 320 kg/m^3 in heartwood (Hirakawa et al.,2003). The PLW decreased slightly with RW (Fig.9), but it is not clear

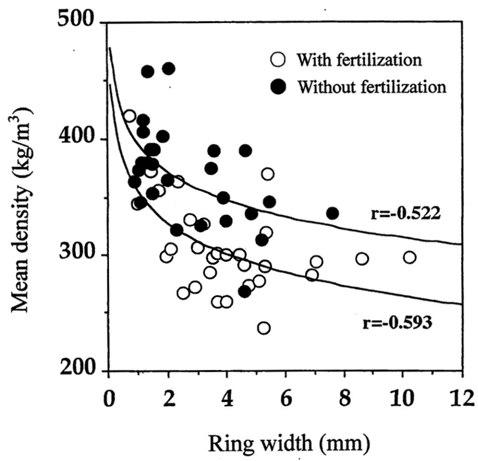

Fig. 8. Relationship between annual ring width (RW) and mean density(MD).

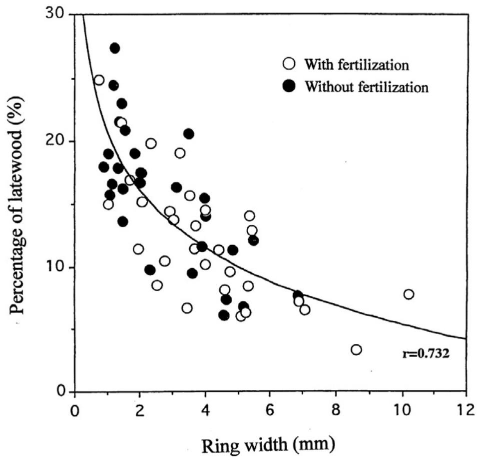

Fig. 9. Relationship between annual ring width (RW) and percentage of latewood (PLW).

whether or not this relation depended on the influence of fertilization.

The variation pattern of RW to PLW found in Fig.9 seems to depend on growing conditions. Hirakawa et al. (2003) reported that PLW ranged from 8 to 40 percent and it was less in juvenile wood than mature wood, with a usual average value of approximately 20 %. In the present experiment, the average was less than 15 %.

3.6.3 Relations of annual ring width to earlywood density and latewood density

Fig. 10 shows the relation between RW, and EWD and LWD respectively. The EWD and LWD were independent of RW, with EWD ranging from 200 to 400 kg/m^3 and LWD from 600 to 800 kg/m^3. The EWD was significantly reduced by fertilization while LWD was hardly affected by it. The reason why a significant fertilization effect was found in EWD appears to be that earlywood cells with thin cell walls were formed by fertilization..

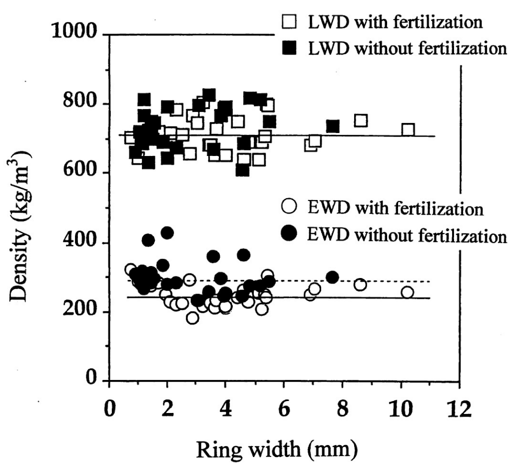

Fig. 10. Relationship between annual ring width (RW), earlywood density (EWD) and latewood density (LWD).

3.6.4 Relations of mean density to earlywood width, latewood width, earlywood density and latewood density

Figs. 11 and 12 show the relations between EW and MD, and LW and MD respectively. The MD decreased slightly with increase of EW. The EW ranged from 0.7 to 7 mm without fertilization, but usually ranged from 1 to 5 mm. The EW with fertilization ranged from 0.6 to 9.4 mm and was larger than without fertilization. The LW was independent of MD and was in a narrow range of 0.15 to 0.8 mm irrespective of fertilization. The LW in sugi was usually less than 1 mm, but values above 2 mm have been reported (Kubo & Jyodo, 1996). MD was found above 310 kg/ m^3 in without fertilization trees, but usually less than 310 kg/ m^3 in with fertilized trees.

Figs. 13 and 14 show the relations between EWD and MD, and LWD and MD respectively. A high positive correlation was found between EWD and MD irrespective of fertilization. In without fertilization, EWDs ranged from 230 to 430 kg/ m^3, most of them from 250 to 300 kg/ m^3. In most fertilized trees EWDs were usually less than without fertilization and had a narrow range from 180 to 320 kg/ m^3. There was no correlation between LWD and MD.

No correlation was found between MD and either

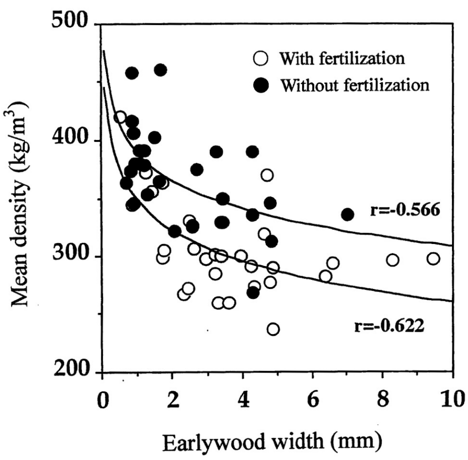

Fig. 11. Relationship between earlywood width (EW) and mean density (MD) .

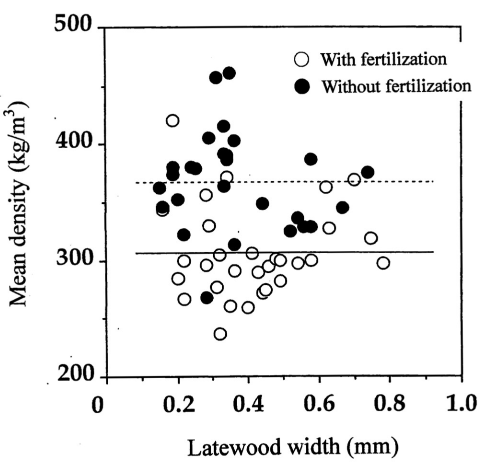

Fig. 12. Relationship between latewood width (LW) and mean density (MD) .

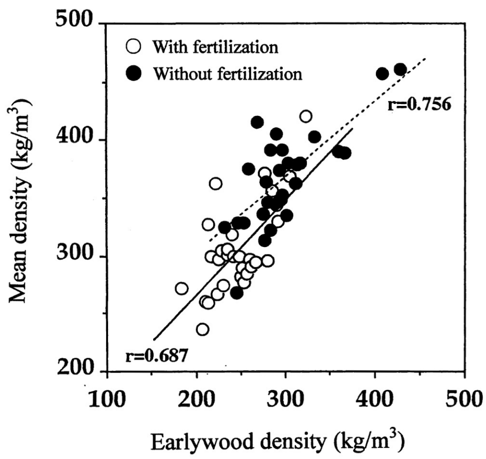

Fig. 13. Relationship between earlywood density (EWD) and mean density (MD) .

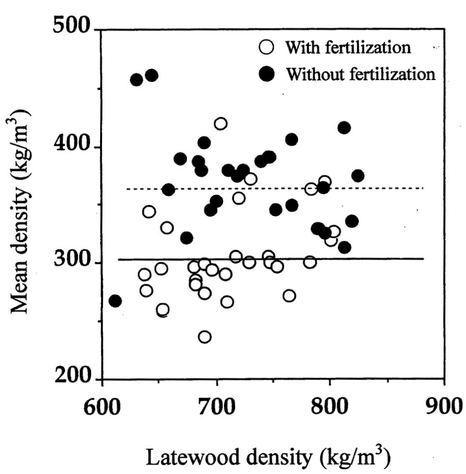

Fig. 14. Relationship between latewood density (LWD) and mean density (MD).

LW or LWD (Figs. 12 and 14), however, MD tended to decrease with EW (Fig. 11) and increase with EWD (Fig. 13). These tendencies were found irrespective of fertilization, while MD was lowered by fertilization. MD was independent of LWD and LW, and was affected by EWD and EW significantly. Similar results were reported by Yazawa et al. (1957) and Fujiwara (1995).

3.6.5 Relations of earlywood density to minimum density, and latewood density to maximum density

As shown in Figs. 4 and 5, the variation patterns in EWD and MinD, and in LWD and MaxD, respectively were very similar. High positive correlations were found between EWD and MinD (r=0.907** for non-fertilization, r=0.898** for fertilization), between LWD and MaxD (r=0.950** for non-fertilization, r=0.908** for fertilization) both with and without fertilization. Additionally high positive correlations were also found between MD and EWD (Fig.13), EWD and MinD, and MD and MinD (r=0.762** for non-fertilization, and r=0.691** for fertilization) both with and without fertilization.

3.6.6 Relation of earlywood density to latewood density

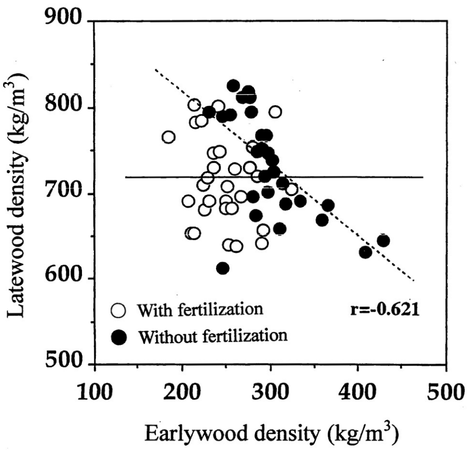

Fig. 15. Relationship between earlywood density (EWD) and latewood density (LWD).

Fig. 15 shows the relation between EWD and LWD. In the fertilized trees there was no correlation between the two, while LWD tended to decrease linearly with increase of EWD in non-fertilized trees. As it is generally known that there is no relationship between the two, the reason for the relationship in this study is not clear.

Conclusions

1. In fertilization without cultivation, values of RW and EW tended to be wider and MD, EWD, Min.D and PLW lower. Significant differences were caused in annual ring structures by fertilization. In cultivated trees, only MinD was lowered by fertilization. This shows that the fertilization effect may have been cancelled out by cultivation. It seems that MD is the indicator reacting sensitively to changes in nutritional circumstances such as fertilization.

2. As for soil effect, in non-fertilized trees, LW, LWD, EWD and MaxD of the Higashi-Kanbara-7 clones grown in paleo-volcanic soil were higher than in the quaternary diluvium soil, while MD, EWD and MinD were lower. Fertilization had no effect on the annual ring structures of Higashi-Kanbara-7 clones grown in these soils.

3. With regard to the clone effects, there was no difference in annual ring structure between clones in trees, regardless of fertilization.

4. RW in fertilized trees was wider than without fertilization.

5. LW was almost constant irrespective of fertilization and aging.

6. LWD and MaxD were almost constant irrespective of fertilization and aging. However, EWD and MinD were always higher in non-fertilized than in fertilized trees.

7. LW increased very slightly with an increase of RW and the increase in RW mostly depended on earlywood both with and without fertilization.

8. MD and PLW decreased slightly with increase of RW regardless of fertilization.

9. There were no correlations between RW and either EWD or LWD.

10. MD was independent of LW and LWD and increased slightly with an increase of EW. MD and EWD were positively correlated.

11. In the fertilized clones, no correlation was found between EWD and LWD, however, EWD tended to decrease with increase of LWD in clones without fertilization.

12. It became clear that some fertilization effect continued in RW, EW, MD, EWD, MinD and PLW for at least 3 to 4 years after the stoppage of fertilization.

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スギクローンの年輪構造に及ぼす施肥、培土及び耕耘の影響

今井 由起[1)]・故三城 昭義[1)]・平川 泰彦[2)*]・丸山 幸平[1)]

要 旨

スギの精英樹 2 クローン（東蒲原 7 号と岩船 4 号）の若木を 1 m^3 コンクリートポットで 10 年間施肥し、年輪構造を指標に施肥の有無、培土の違い（第四紀洪積層土壌と古火山灰土壌）及び耕耘の有無の影響について調べた。施肥により無耕耘区と耕耘区の双方で最小密度が低下していたが、無耕耘区ではさらに年輪幅の増加や年輪内平均密度などの低下も認められた。また、培土による影響は、無施肥区で認められたが施肥区では認められず、培土の本来の生産力の影響は施肥効果より上回っていた。さらに、クローンの違いによる影響は、施肥、耕耘及び培土が異なっても認められなかった。これらの結果は、施肥の効果はクローンには関係がなく生産力の低い培土で現れやすいことを示している。しかし、耕耘の効果については、施肥区で最小密度が増加するなどの事例が認められたものの、その理由を明らかにすることはできなかった。施肥による年輪構造への影響は、早材幅の増加による年輪幅の増加と早材密度と最小密度の低下に伴う年輪内平均密度の低下として現れており、施肥により細胞壁厚の薄い早材細胞が形成される効果があったことが考えられる。また、年輪幅、早材幅、平均密度、早材密度、最小密度及び晩材率に対する施肥の持続効果は 3 ～ 4 年間続くものと推定した。

キーワード：施肥、第四期洪積世土壌、古火山灰土壌、耕耘、スギ、年輪構造

* 森林総合研究所木材特性研究領域　〒 305-8687　茨城県つくば市松の里 1　e-mail: hirakawa@ffpri.affrc.go.jp
1) 元新潟大学農学部
2) 森林総合研究所木材特性研究領域