The effect of thinning on the branch diameter increment in pine stands

VEIKO URI
Estonian Agricultural University
Faculty of Forestry
Kreutzwaldi 5, EE 2400 Tartu, Estonia

Uri V. 1998. The effect of thinning on the branch diameter increment in pine stands. *Baltic Forestry*, 1: 17-23

Intermediate cutting is one of the basic measures of silviculture as well as an important source of timber. In order to maximize gain from each intermediate cutting, the knowledge of the response of the forest as a self-regulating system to thinning is indispensable.

The aim of the present study was to investigate the effects of thinning on the diameter increment of branches in the pine stand. The influence of thinning was established on the basis of the radial increment. A general growth function describing the annual increment of branches was developed.

It has been found that thinning is affected by the branch increment distribution. The radial increment of branches depends on breast height diameter of the tree, age of the branch and its position in the whorl. In the Kuuste stand the branch diameter increment increased approximately 16% after thinning. It is noteworthy, that recent annual rings are missing in older branches. Thus, although branches are alive, their diameter does not increase. This may be caused by different light conditions in the crown; the allocation pattern of assimilates as well by static load factors.

Key words: effect of thinning, the radial increment, branch diameter growth, growth function

Introduction

The effect of thinning on stand growth, particulary on the diameter increment of stems, is one of the main thoroughy investigated problems of silviculture. The majority of authors have found that thinning has a positive effect on the growth of trees, at least when it is performed in accordance with the principles of silviculture. As a rule, trees respond to improved light and root nutrition conditions with the increase in the growth and radial increment intensity after thinning (Tullus 1988). For example, the positive effect of thinning can be observed 5...6 years (Uri 1994) or even 8...10 years (Tullus 1992) after thinning. Theoretically, it can be supposed that branches of trees react to improved conditions similary to stems: better light conditions in the canopy lead to more intensive photosynthesis, the amount of assimilates increases and branch growth intensifies. Light is one of the main factors affecting the morphology and structure of the tree crown (Doruska, Burkhart 1994). This line of reasoning underlines the point of view that thinning decreases to a certain extent the quality of timber, as thinned stands are branchier, i.e. branches grow thicker and persist on trees longer (Smith 1962). In the present paper we attempt to test this statement and evaluate the effects of thinning on the diameter increment of branches in pine stands (*Pinus sylvestris*). Most authors have investigated crown structure and branch growth on the basis of the dynamics of branch diameter and length. Doruska and Burkhart have studied crown structure on *Pinus taeda* (Doruska, Burkhart 1994). Kurttio and Kellomäki have studied crown structure as well as branch growth and their relationship with other parameters of *Pinus sylvestris* (Kurttio, Kellomäki 1990).

The aim of the present work was to study the effects of thinning on the diameter increment of branches as based on the radial increment before and after thinning, as well as to find out whether a considerable increase occurs in branch diameter increment after thinning. Gavrikov dealt with the radial increment in his study describing the growth of Norway spruce branches (Gavrikov 1996). He derived several growth curves which characterize an increase in the branch diameter increment but did not succeed in elaborating mathematical models that would describe the dynamics of the branch diameter increment. In order to study the effect of thinning on branch growth, first it is necessary to elucidate the general branch growth. Therefore, a major part of the present paper is devoted to the elaboration of mathematical models describing branch growth, which is indispensable for the solution of the main problem of the study.

Material and methods

Data for the present study were collected in Järvselja experimental forest district and in the Kuuste forest district Estonia, in 1993...1994. Four sample plots were used, two of them thinned (in 1982 and 1991) and two unthinned. Thirteen model trees were felled on the Kuuste study plot and twelve on each of the three Järvselja sample plots. Before felling, the frequency distribution of diameters was calculated. Model trees were selected on the basis of diameter distribution proceeding from the principle that selection should characterize the whole stand. Table 1 gives the essential data on study plots. Study plots No.2 (thinned) and No.3 (control plot) were located in the same subcompartment. Before thinning, both plots were homogeneous. Study plot No1 in Järvselja was an unthinned stand of high density, which made it possible to describe the general increase in the radial increments of branches.

Table 1. The data of sample plots

Stand characteristics, unit.	Kuuste	Järvselja		
		Sample plot No.1	Sample plot No.2	Sample plot No.3
Year of measurement	1993	1994	1994	1994
Number of model trees	13	12	12	12
Year of thinning	1982	-	1991	-
Stand age, y	44	31	33	33
The average diameter, cm	13.6	17.1	14.8	14.3
The average height, m	16.4	17.1	15.0	13.6
Site index	II	Ia	Ia	Ia
Number of trees per ha	1636	1420	1465	2140
Density	0.7	1.0	0.8	1.0
Thinning, %	38	-	24	-
Site type	*Rhodococcum*	*Myrtillus*	*Myrtillus*	*Myrtillus*

Due to the lack of a control plot it was hard to determine the effect of thinning in the Kuuste stand. The main parameters of felled trees were measured and the average branch of each whorl was used as a model branch. A branch cross section was sawn at the basal end of the model branch in the middle of the first-year annual shoot (Fig.1). The radial increments of 425 branch cross sections were measured using a special binocular-electronic equipment with the accuracy of 0.01mm.

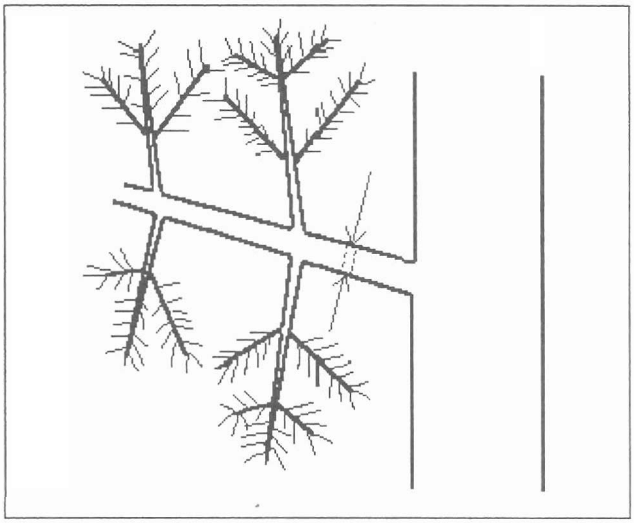

Fig. 1. The location of the cross section on the branch

Statistical methods: ANOVA and regression analysis were used. Both linear and nonlinear models were adapted to the data. The distribution of sample data was estimated according to c^2 -criteria. The t – test was applied to compare the mean values. Both one-way analysis of variance and multifactorial analysis of variance were used. In case the ANOVA requirements were not fulfilled e.g. the distribution of a variable was significantly different from normal, or the variances of different groups were not equal the Kruskal-Wallis nonparametric analysis was applied.

Results and discussion

While checking the absolute distributions of the annual radial increments with the help of c^2-criteria for normality, it became evident that in case of the Kuuste sample plot the distribution of the radial increments before thinning (1982) approached normal distribution (significance level $p > 0.05$), whereas after thinning (since 1984) it differed significantly from both normal and lognormal distribution. The same result was achieved when analysing stem the radial increments of stems: before thinning annual distribution of the diameter increments at breast height could be approximated by lognormal distribution; after thinning this dependency disappeared and the distribution differed significantly from normal as well as from lognormal distribution.

Studies on the radial increment distribution of branches taken from the Järvselja thinned study plots produced the same results. These results were compared to the corresponding data of control plots. The annual distributions of the radial increments on thinned plots could be approximated by normal distribution before felling but not in the first and second year after thinning. Three years after thinning the distribution approached again normal distribution. While comparing the results with those obtained from control plots and study plot No. 1 (unthinned stand), it became evident that in the above-mentioned stands the distribution approached normal or lognormal distribution over the whole period of study. Thus one can draw the following conclusion: although the effect of thinning on the diameter growth of branches may be minimal, its effect on increment distribution is evident. The dimensions of living organisms, including trees serve as a classical example of characteristics subjected to normal distribution, because the growth of trees is affected by several environmental factors. If these factors are stable the system is stable as well. By thinning environmental conditions in the stands are changed and, consequently, the system becomes unstable. As a result of a response elicited by the stand changes occur in the growth until a new – stable state is achieved. Thinning is not an incidental factor of minor importance but an essential element that affects the whole distribution. The situation where increments on the Kuuste sample plot cannot be approximated by normal distribution before the 9th year after thinning and in Järvselja already in the 3rd year after thinning can be explained by differences in sites. The Järvselja sample plots are situated on former agricultural land, whereas the Kuuste sample plot represents the *Rhodococcum* site type. The site index of Järvselja is I[a] and that of Kuuste, II. Structural changes brought about by thinning are more rapidly restored in more favourable growth conditions.

In the course of the measurement and analysis of the branch radial increment of Scotch pine it has been found that in older branches, recent annual rings are missing or they are so narrow that it is impossible to distinguish them. For example, when studying the 6th branch whorl from the top, whose age was six years, the expected number of annual rings on the basal area of the branch would have been six. However, this was not always the case. Thus, although branches are alive and bear assimilating needles, the diameter growth of branches is retarded. Gavrikov who noticed a decrease in the number of annual rings in Norway spruce branches, has described this phenomenon in his study (Gavrikov 1996). Despite diameter growth cannot be traced in the basal area of the branch, this does not mean that it does not take place in any other branch area (the problem is not discussed in the paper). While studying diameter growth along the branch at different relative distances from the stem, Gavrikov found the maximum annual ring area a few whorls from the top of the branch (Gavrikov 1996). This phenomenon cannot be explained merely by light deficit (in the lower part of the canopy there is less light, the growth of branches is retarded and finally they die), because annual rings are missing not only on the branches of the lower layers but also on the branches of middle and even upper layers (Fig. 2). If the absence or retardation of the increment depends only on light

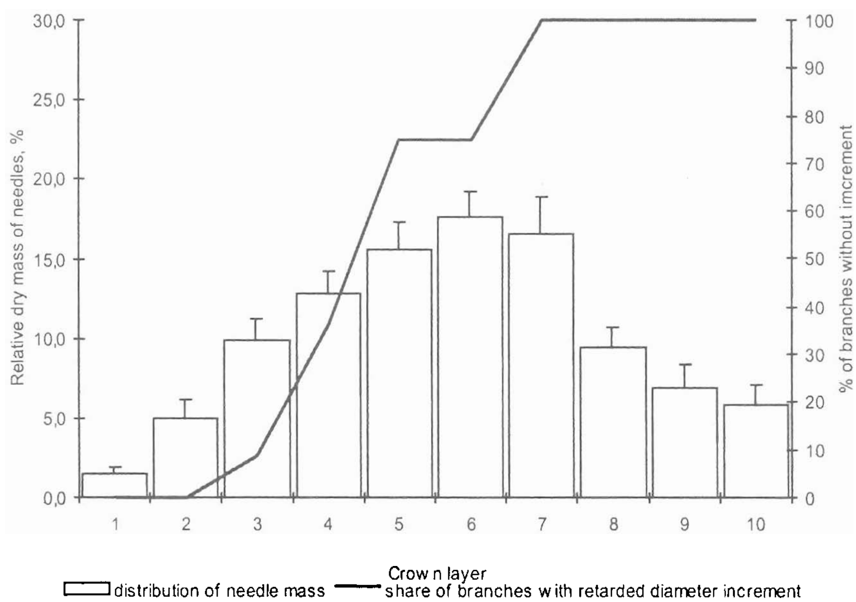

Fig. 2. Distribution of relative needle mass and cessation of annual increment over crown layers

conditions, a decrease in the number of annual rings must be related to the loss of needle mass in the crown.

Along with the branch radial increment, relative needle mass distribution in the crown was also analysed on the basis of the data collected from Järvselja sample plot No.1. The crowns of the studied trees were divided into ten equal layers, and from each layer a model branch was selected for the estimation of needle mass. Figure 2 presents the distribution of relative needle mass in the crown. It appears that needle mass is in its maximum in the middle part of the crown. Although these branch whorls are not dying, their branch radial increment is still retarded. Other researchers have also described an analogous needle mass distribution in the crown (Anniste 1997, Kollist 1970, Tullus and Tamm 1992). It has also been noted that the vertical distribution of needle mass in pine trees mainly depends on stand density (Anniste 1997). The needle mass of the middle part of the crown forms (regardless of the age of the stand) approximately half of needle mass (Anniste 1997, Kollist 1970). However, the stand brings about a decrease in the share of the lower third of the crown and an increase in the share of the upper third in needle mass. This can be explained by certain priorities that are revealed in the growth of the tree: assimilates are used first of all for primary root and sprout growth, then for the development of generative organs and only at the end for diameter growth of branches and stems.

In boreal forests, more than 60% assimilates can be transported into fine roots (Persson 1983). Evidently, the assimilates produced by branches in middle layers would be sufficient for diameter growth, but these assimilates are transported into other parts of the tree: fine roots, top of the crown and meristem tissues. In order to guarantee maximal growth of the whole tree, produced biomass is alloted between different tree parts: needles, branches, roots and stem (Kofman 1986). As competition in stands is realized through height growth, a large amount of assimilates is directed to the upper layers of the crown. Mechanical theories describing branch and stem growth rely on the relationship between the branch (stem) diameter, weight and length. Thus, the diameter of the branch close to the stem is dependent on branch length and weight and is related to static load affecting the branch. The longer the branch grows and the bigger mass it has, the longer must be its diameter (Farnsworth, Gardingen 1995).

Pruning within a branch is similar to pruning process in the whole tree. Older branches in the middle and lower layers of the crown get less light, a part of needles and shoots die, and the mass of older branches diminishes. This tendency also can account for the absence of annual rings on older branches. In accordance with the static load theory (Farnsworth, Gardingen 1995) there is no need for the branch to increase its diameter, because branch mass does not enlarge any more but even decreases. The absence of annual rings on branches from the lower layers of the crown can probably be explained by the fact that needle mass in this part is small and the amount of assimilates transported into the branch is only sufficient for the branch to survive. Krigul's study in which he found that the removal of the lower branches of the crown does not affect the increment of trees confirms this statement (Krigul 1961,1968).

To elucidate the factors increasing the secondary growth of branches, analysis of variance was used. It was presumed that the branch radial increment depends on the number of the branch whorl (counting from the top of the crown). Through the branch whorl, the growth of a branch is related to two characteristics: age of the branch and its location in the crown. Multifactorial analysis of variance has shown that both the diameter of the tree at breast height and the location of the branch whorl has a significant effect on branch diameter ($p<0.05$). This regularity is revealed in case the data are collected from all four sample plots. Branch length also depends on the size of the tree and on the branch whorl number. Here allometric relationship is obvious: during growth process the tree retains its shape; the bigger the tree, the thicker and longer its branches. Several physiological theories describing the growth and form of stems, for example, the theory of partitioning of assimilates and "pipe" theory have attempted to explain this. In accordance with the latter theory there is a strong positive correlation between the photosynthesizing mass and sapwood area. Particularly strong correlation occurs between stem diameter under the crown and the needle mass (Kofman 1986). Although these theories describe the growth and form of stems, they might be applied to branches as well. Farnsworth and Gardingen have made a more specific use of allometric relationship to test different theories. They compared the applicability of "pipe" theory and static load theory to Sitka spruce *Picea sichensis* (Farnsworth, Gardingen 1995). The first is a physiological theory based of the movement of water in the plant while the latter is a mechanical theory which assumes that branch diameter is determined by the total needle mass and needled sprouts. We have found that the latter theory suits best Sitka spruce.

The effect of branch age is probably similar to that of tree age. Presumably, there exist a general growth curve, and the growth is certainly affected, mainly via light conditions by the location of the branch in the crown. Thus it can be concluded that branch growth depends on stem diameter, branch age, the hierarchic position of the branch in the crown and probably also on metereological conditions. There are several other factors that have affected the branch radial increment to a smaller or greater extent. This causes a great variation in the data,and that is why it would not be correct to use absolute values of the radial increments in further analysis. In order to reduce the variability caused by the difference in trees and to single out the effect of thinning from among the multitude of other influences the relative scale has been used. The relative increment has been calculated from branch diameter by dividing the increments of different years by branch diameter.

$$\Delta R\% = \frac{2\Delta R_{abs}}{D} \quad (1)$$

$\Delta R\%$ – relative increment of radius
ΔR_{abs} – absolute increment of radius
D – branch diameter

The relative increment expresses the share of the increment from branch diameter (in percent). Further analysis of diameter growth was based on the relative diameter increment of model branches in a certain year. A regression equation which describes branch growth in different years depending on the age of branches and their position in the crown has been found. The following allometric equation describes the dependence of branch relative increment on its age:

$$\ln y = a + b \ln x \quad (2)$$

where *y* refers to relative radius increment (D%), *x* is the number of the branch whorl i.e. age of the branch, *a*, *b* are equation parameters

While analysing parameters a and b from equation (2) it has been found that their absolute values increase with a decreasing number of years: the smaller the year number, the wider the annual rings of the branch.

The regression equation describes the change in the increment in a branch whorl: the higher the branch is located, the younger it is and the more intensive is its growth. On the contrary, the older and lower the branch whorl, the smaller its increment. The theoretical basis of this phenomenon is the theory of partitioning of assimilates. The upper part of the crown, where intensive height growth takes place, is supplied first of all. The assimilates of the lower layers are not relocated on the top, because they do not participate in height growth and thus do not play a crucial role either in the growth intensity of the whole tree or in competition ability. Equations (3) and (4) describe branch growth on the Kuuste sample plot during the whole study period, but is not accurate enough for data from the Järvselja sample plots.

The model is as the following:

$$\ln a(YEAR) = 26.0 - 5.43 \ln(YEAR), \quad (3)$$
$$\ln b(YEAR) = 19.1 - 4.14 \ln(YEAR), \quad (4)$$
$$\ln Dr(YEAR) = a(YEAR) + b(YEAR) \ln WNR \quad (5)$$

YEAR denotes two last digits of the year number
WNR denotes the number of the branch whorl i.e.age of the branch

For equations (3) and (4) $p<0.00001$ and $r^2>0.9$

This model describes adequately branch growth in Kuuste but is not sufficiently exact in case of the data for the Järvselja sample plots.

The above model describes relative diameter growth. Therefore, we attempted to find the relationships between the absolute values of branch diameter, tree diameter at breast height and the number of the branch whorl (i.e. age of the branch and its position in the crown). This relationship is described by equation (6)

$$BDM = 0.0557 D_{1.3}^{0.946} WNR^{0.420} \quad (6)$$

BDM – diameter of branch, mm,
$D_{1,3}$ – tree diameter at breast height, mm,
WNR – number of the branch whorl,
$r^2 = 0.77$, and $p < 0.00001$

The model of relative growth (3;4;5) was used to estimate the influence of thinning on the diameter growth of the branch. Presumably, as in case of the stem, a general growth curve can be applied to branches. However, as there was no control for Kuuste sample plot, we could not compare branch growth on thinned and unthinned areas.

To study the effect of thinning, the influence of the general growth curve on the thinned area should be eliminated. For this, it is necessary to eliminate the trend of the growth from the effect of thinning. For the analysis of the thinning effect only the data on branches that existed at least five years before thinning were used.

Their increments during the period of five years before and after thinning were compared. The relative radial increment till the year of thinning was modelled. Thus we obtained a growth curve which describes branch growth before thinning. The growth curve was the following:

$$\ln y = 44.89 - 9.76 \ln YEAR \quad (7)$$

YEAR denotes the two last digits of year number $p<0.00001$ and $r^2 >0.9$

This trend characterizes growth in the absence of the effect of thinning. By comparing growth curve to the increment after thinning it is possible to estimate the thinning effect on the radial increments. Table 2 and Figure 3 illustrate the obtained results.

Table 2. The modelled and actual values of the branch radial increment on the Kuuste sample plot

Years	The mean relative increment, %		
	Modelled	Actual	Difference
1982	6.65	6.90	0.25
1983	5.91	6.84	0.93
1984	5.25	6.30	1.05
1985	4.68	5.72	1.04
1986	4.17	5.11	0.94
1987	3.73	4.54	0.81

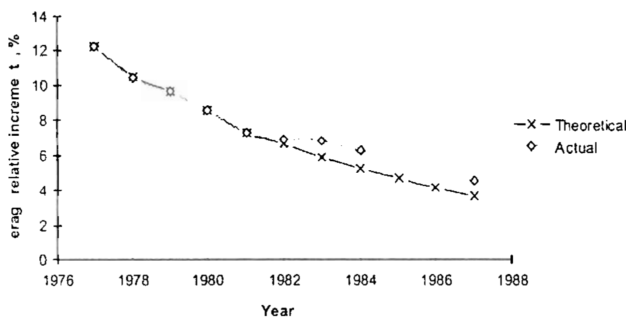

Fig. 3 Growth curve and the actual relative radial increments of branches on the Kuuste study plot before and after thinning

The application of the described method allows us to evaluate the effect of thinning on branch diameter growth. It turned out that thinning affected diameter growth most of all in the period of four years after thinning when the actual increment was 18.2% larger than the theoretical one. The mean actual relative diameter increment on average is 16% larger than the corresponding parameter theoretically five years after thinning, which is due to the effect of thinning.

This result is in good accordance with the results of similar studies on the diameter increment of tree stems. It should be noted that after thinning the diameter increments of tree stems on average increased 16% (Tullus 1985) as compared to these before thinning.

This method does not allow us to draw reliable conclusions on branches that have grown after thinning. In order to analyse branch growth after thinning the existence of a control plot is indispensable.

The model describes more than 90% of the variance in branch growth on the Kuuste sample plot, whereas in case of the Järvselja sample plots (better site type stands) the prediction level of the model is by far lower. For these plots, the effect of thinning was studied by using allometrical parameters. No statistically significant differences were found when comparing the effect of thinning on branch diameter increment on thinned and control plots.

Conclusions

1. Thinning affects the distribution of the relative increment of branches. Before thinning, increment distribution can be approximated by normal or lognormal distribution, whereas after thinning, this regularity disappears for a certain period of time.

2. It became evident that older living branches do not always produce annual rings in the basal area of the branch. This tendency can be explained by light conditions in the crown, static load theory as well as by the priorities of the tree in assimilate partitioning.

3. The diameter increment of branches in a stand depends on tree diameter at breast height, the age of the branch and its location in the crown. Allometric equations describing branch growth are presented in model (5).

4. A new method which makes use of modelled and actual radial increments allows us to evaluate the effect of thinning on plots in the absence of control, was worked out. The advantage of the method is that, unlike for sample plots supplied with control areas, only one stand is studied. Hence there will be no differences in growing conditions before thinning (externally similar stands grow differently). The disadvantage is the fact that in the extrapolated part of the curve the effect of actual weather conditions is not taken into account (earlier influence of weather conditions being extrapolated)

5. The effect of thinning on the diameter increment of branches is variable. When processing the data

gathered from the Kuuste sample plot it became evident that in the period of five years after thinning, the branch increment on average increased 16%. As to the Järvselja sample plots, the effect of thinning on the branch increment was not established.

References

Anniste J. 1997. Okkamassi hulga ja jaotuse määramine puhtmännikus [Determination of foliage biomass and vertical distribution in a pure pine stand]. EPMÜ teadustööde kogumik, 189: pp. 168-200 (in Estonian).

Doruska P. F., Burkhard H. E. 1994. Modeling the diameter and location of branches within the crowns of loblolly pine trees in unthinned plantation. Canadian Journal of Forest Research, 24: 2362-2376.

Farnsworth K. D., Van Gardingen P. R. 1995. Allometric analysis of Sitka spruce branches: mechanical versus hydraulic design principles. Trees, 10: 1-12.

Gavrikov V. 1996. Distribution of wood increment along branches of 9-years-old Norway spruces (*Picea abies* [L.] Karst.). Centralblatt für das gesamte Forstwesen, 113: 1-11.

Kollist P. 1970. Männi okkamassi seosest puu dimensioonide ning juurdekasvuga kuivendatud soometsades [Relationship between the needle mass of pine and tree dimensions and increment in a drained swamp forest]. Metsanduslikud uurimused, 8: pp. 49-75 (in Estonian).

Krigul T. 1961. Männi- ja kuusepuistute laasimine [Pruning of pine and spruce stands]. Eesti Loodusteaduste arhiiv, Tartu, 194 (in Estonian).

Krigul T. 1968. Laasimise rakendamisest metsamajanduses [Application of pruning in forest management]. EPA teaduslike tööde kogumik, 50: pp. 121-137 (in Estonian).

Kurttio O., Kellomäki S. 1990. Structure of young *Pinus sylvestris*: branching and its dependence of tree size. Scandinavian Journal of Forest Research, 5: 169-176.

Persson H. 1983. The distribution and productivity of the fine roots in boreal forests. Plant and Soil, 71: 87-101.

Smith M. D. 1962. The practice of silviculture. New York, 578 p.

Tullus H., Tamm Ü. 1992. Okkamassi iseloomustus keskealistes männikutes. [Characterization of needle mass in middle-aged pine stands]. Metsanduslikud uurimused, 25: 71-73 (in Estonian).

Tullus H. 1988. Harvendus- ja põimendusraiete mõju puistute kasvule [Effect of harvesting thinning on the growth of stands]. Tallinn, Valgus, pp. 60-68 (in Estonian).

Uri V. 1994. Harvendusraie mõju puude diameetrite juurdekasvule keskealise männiku näitel [Effect of thinning on branch diameter increment in a middle-aged pine stand]. EPMÜ teadustööde kogumik, 173: pp. 144-149 (in Estonian).

Кофман Г. Б. 1986. Рост и форма деревьев [The growth and form of trees]. Наука. Новосибирск, 210 pp. (in Russian).

Туллус Х. 1992. Прирост диаметра на высоте груди в средневозрастных сосняках после разреживания [The diameter growth in middle-aged pine stands after thinning]. Metsanduslikud uurimused, 24: pp. 86-92 (in Russian).

Received 12 March 1998

ВЛИЯНИЕ РАЗРЕЖИВАНИЯ НА РОСТ ВЕТВЕЙ СОСНЫ В ТОЛЩИНУ

В. Ури

Резюме

Разреживание является одной из важнейших лесоводственых мер и служит важным источником получения древесины. Чтобы от каждой рубки ухода получитъ максималный доход, важно знат, как лес в качестве саморегулирующейся системы реагирует на разреживание. Главная целъ настоящей работы заключалась в выяснении влияния разреживания на рост ветвей сосны обыкновенной в толщину. Влияние выяснили на основании радиалъных приростов ветвей. В ходе работы разработали описывающую рост ветвей математическую моделъ, которая была необходима для решения основной проблемой исследования. Выяснилось, что радиальный прирост ветвей зависит от диаметра дерева на высоте груди, возроста ветви и расположения ветви в кроне. В изучаемом насаждении прирост диаметра ветвей увеличился после рубки приблизително на 16%. Примечателен факт, что у более старых ветвей отсуствуют годичные копьча последних лет. Тем самым, хотя ветви и живы и имеют фотосинтезирующую хвойную массу, прирост этих ветвей в толщину заторможен. Названное обстоятельство может быть обусловлено различными световыми условиями, распределением ассимилатов и статической нагрузкой.

Ключевые слова: влияние разреживания, рост ветвей, радиалъные приросты, функция роста.