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# Silva Fennica

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# VARIATION IN STRUCTURE AND SELECTED PROPERTIES OF FINNISH BIRCH WOOD: III. PROPORTION OF WOOD ELEMENTS IN STEMS AND BRANCHES IN BETULA PENDULA ROTH

K. M. BHAT and MATTI KÄRKKÄINEN

*Seloste:*

*SUOMALAISEN KOIVUPUUN RAKENTEEN JA ERÄIDEN OMINAISUUKSIEN VAIHTELU III. RAUDUSKOIVUN RUNGON JA OKSIEN SOLULAJIEN RUNSAUSSUHTEET*

Saapunut toimitukselle 1981-01-19

Variation of the cellular proportion within the same growth rings counted from the pith of the stems and branches in four trees of *Betula pendula* was studied. The fibre percentage decreased from breast height to the crown and then increased in the branches. The reverse trend was found in the percentage of vessels and parenchyma, although the percentage of the latter varied relatively little. No statistically significant differences were found in the proportion of cells either between the stems and branches or within the branches from the base to the tip and upper to lower radius.

By using quadratic and interaction terms of age, growth rate, diameter growth, height level in the trunk and distance from the branch base, the best models were chosen to explain the variation in cellular proportions. About 49 % of the variation in fibre proportion was explained in the stems and 61 % in the branches. Similarly, 37 % of the variation in vessel proportion was accounted for in the stems and 49 % in the branches. 56 % and 47 % of the total variations in parenchyma proportion were accounted for in the stems and branches, respectively.

## INTRODUCTION

Interest in the cellular proportion of trees is increasing because many tree improvement programmes use the proportions of different cell and tissue types, like fibres and rays as selection criteria. The proportion of fibres is, in particular, important in pulping.

A few reports are available on the proportion of vessels and fibres in birch wood. As early as 1892, STAUFFER reported that in birch, growth rings become "vessel rich" as the stem height increases and later studies have confirmed this finding (e.g. KASESALU 1965). WALLDEN (1934) supported this view, and established a negative correlation between the percentage of vessel proportion and basic density. KUJALA (1945) concluded that the vessel percentage decreases from the pith to the bark.

With the present trend of using stems and even branches from the trees of short rotation management, wood property variation in the juvenile stage and top part of the trees merits more attention than it has been devoted in earlier studies. The purpose of this study, therefore, was to investigate the variation of cellular proportions, such as fibres, vessels and parenchyma, in stem formed wood of early stage and crown formed wood including a branch. *Betula pendula* Roth trees were selected for the study.

The material was collected by Bhat with the assistance of A. Wäänänen. Bhat also carried out the laboratory work and wrote the original manuscript which was checked by both authors. Kärkkäinen computed the results. The manuscript was typed by Aune Rytkönen. The English text was revised by L. A. Keyworth.

Bhat wishes to express his gratitude to Prof. Bror-Anton Granvik and the staff of the Department of Logging and Utilization of Forest Products for providing the necessary facilities and the Ministry of Education, Finland for financial support.

## MATERIAL AND PROCEDURE

Four dominant or co-dominant, straight mature trees were selected in a natural stand near the Forestry Field Station, University of Helsinki, Hyytiälä (61° 51'N 24° 16'E). The trees were felled and cross sectional discs were removed from the trunk at breast height and in the crown region. The sampling point in the crown was chosen to include a branch from the same height level in each tree. However, the exact location of sampling was shifted about 30 cm above the point of insertion of the branch into the stem in order to avoid any abnormality.

In addition to the basal discs removed at 15 cm above the point of insertion to the trunk, transverse discs were cut from the branches at 25 %, 50 % and 75 % lengths. Thus, two trunk discs, representing stem formed wood and crown formed wood and four branch discs were taken for study from each tree.

About 15 degree wedges were cut from both the upper and lower radii of the branches in addition to the wedges removed from the random radius of the trunk discs. Using a sliding microtome, transverse sections of about 15–20 $\mu$m thickness were cut from the small segments, obtained from the wedges, showing the 1st, 5th, 10th, 15th, 20th and 25th growth rings from the pith. The sections were stained with safranin for microscopic observation.

Measurements of the cellular proportions were made according to a point count technique using eye piece graticule (CURTIS 1960). The eye piece graticule has 25 points asymmetrically arranged within a circular field. The proportion of points overlying the image of each type of tissue (vessels, fibres and parenchyma) is statistically proportional to the area occupied by that tissue.

In the present study, the proportion of longitudinal parenchyma was treated with that of rays because of the negligible volume of the former which was confined only to the boundaries of growth rings. Two positions of eye piece per field were taken into consideration in order to increase accuracy (QUIRK 1975). On an average, 250 point counts were made from each of the 230 sampled growth rings for the estimation of cellular proportions. To avoid the radial and tangential gradients of the wood elements, eye piece fields were passed across the growth ring at an angle of 45 degrees to the direction of growth (Fig. 1). The width of the growth ring was measured accurately by using an ocular micrometer.

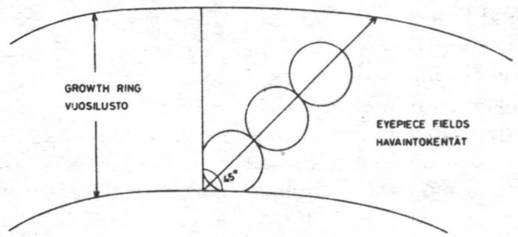


Fig. 1. Sampling lines on growth rings for cell proportions.

*Kuva 1. Vuosilustojen otoslinjat solulajien runsaussuhteiden selvittämiseksi.*

Table 1. Properties of *Betula pendula* trees.

*Taulukko 1. Tutkittujen rauduskoivujen ominaisuudet.*

| Tree No. *Puu n:o* | Tree height m *Pituus, m* | DBH cm (excluding bark) *Kuoreton rinnankorkeusläpimitta, cm* | Trunk diam. at branch height (excluding bark), cm *Puun kuoreton läpimitta oksan kohdalla, cm* | Distance from ground to branch sampling point, m *Korkeus maasta oksan sijaintikohtaan, m* | Branch length, m *Oksan pituus, m* |
|---|---|---|---|---|---|
| 1 | 16,0 | 20,5 | 14,7 | 12,0 | 3,0 |
| 2 | 24,0 | 23,4 | 10,9 | 16,0 | 3,0 |
| 3 | 24,0 | 21,1 | 10,0 | 16,0 | 3,0 |
| 4 | 23,0 | 21,5 | 11,8 | 18,0 | 3.5 |



## RESULTS AND DISCUSSION

### Proportion of fibres

The proportion of fibres decreased from breast height to crown in the bole and then increased in the branch of each of the four trees studied. However, the difference between the mean values of the stems and branches was not statistically significant. The results agree with the reports of earlier studies on birch and European black alder (KASESALU 1969, VURDU and BENSEND 1980). This trend was not clear in the branch from the base to the tip. Further, the difference was not significant between the upper and lower radii although the percentage was a little higher in the upper radius.

The mean values obtained in the present study were smaller than those of the earlier study made by OLLINMAA (1955), who reported 74,2 % and 75,9 % for the stem and branches, respectively. A possible explanation for the difference is that his data were based only on the outermost growth rings of the stems and branches. It is reasonable to assume that mature wood has a higher percentage of fibres than juvenile wood because there is a striking increase in fibre proportion from the pith outwards in both the stems and branches (Fig. 2 and Tables 2 and 3).

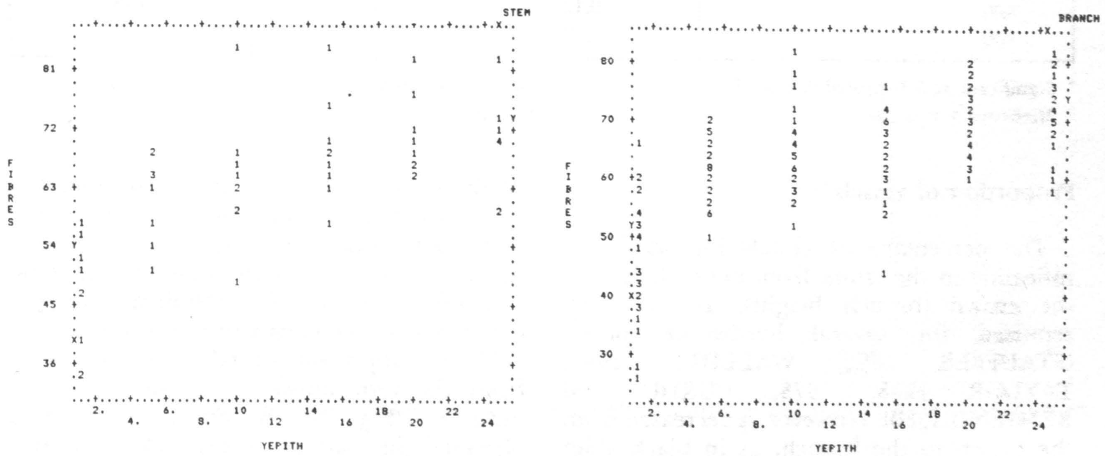


Fig. 2. Fibre proportion according to the number of growth rings from the pith in the stems (left) and branches (right).

*Kuva 2. Kuitujen osuus ytimestä lasketun vuosilustomäärän mukaan rungoissa (vasemmalla) ja oksissa (oikealla).*

Table 2. Means and between tree standard deviations of the percentage of tissues in 4 trees of *Betula pendula*.
*Taulukko 2. Solulajien runsaussuhteiden keskiarvot ja standardipoikkeamat neljän rauduskoivun välillä.*

| Cell type *Solulaji* | Stem *Runko* | | | | Branch *Oksa* | |
|---|---|---|---|---|---|---|
| | Breast height *Rinnankorkeustaso* | | Branch height *Oksan taso* | | | |
| | x̄ | s | x̄ | s | x̄ | s |
| Fibres *Kuidut* | 68,5 | 4,7 | 59,9 | 0,4 | 62,1 | 10,6 |
| Vessels *Putkilot* | 21,5 | 2,9 | 28,1 | 2,7 | 26,7 | 8,0 |
| Parenchyma *Parenkyymisolut* | 10,0 | 2,0 | 12,0 | 2,6 | 11,2 | 4,6 |

Table 3. Correlation coefficients of the stemwood.
*Taulukko 3. Runkopuun korrelaatiokertoimet.*

| Independent variable *Selittävä muuttuja* | Dependent variable *Selitettävä muuttuja* | | |
|---|---|---|---|
| | Proportion of fibres *Kuitujen osuus* | Proportion of vessels *Putkiloiden osuus* | Proportion of parenchyma *Parenkyymin osuus* |
| $x_1$ | 0,64** | – 0,58** | – 0,49** |
| $x_2$ | 0,04 | – 0,23 | 0,32* |
| $x_3$ | – 0,29* | 0,28* | 0,20 |
| $x_4$ | 0,30* | – 0,31* | – 0,15 |
| $x_1^2$ | 0,53** | – 0,48** | – 0,40** |
| $x_2^2$ | 0,00 | – 0,17 | 0,31* |
| $x_3^2$ | 0,27 | 0,25 | 0,18 |
| $x_4^2$ | 0,31* | – 0,31* | – 0,16 |
| $x_1x_2$ | 0,45** | – 0,52** | – 0,13 |
| $x_1x_3$ | 0,19 | – 0,18 | – 0,13 |
| $x_1x_4$ | 0,66** | – 0,61** | – 0,48** |
| $x_2x_3$ | – 0,10 | – 0,05 | 0,36** |
| $x_2x_4$ | 0,12 | – 0,25 | 0,18 |
| $x_3x_4$ | 0,32* | 0,27 | 0,27 |

* Significant at 5 % probability level
*Merkitsevä 5 % tasolla.*

** Significant at 1 % probability level
*Merkitsevä 1 % tasolla.*

## Proportion of vessels

The percentage of vessels increased significantly in the trunk from breast height to the crown (branch height), as has been reported for several hardwood species (STAUFFER 1892, WALLDEN 1934, TAYLOR 1968, 1973, VURDU and BENSEND 1980). However, it decreased from the crown to the branch, as in black alder (VURDU and BENSEND 1980), although the difference between the mean values of the stems and branches was not statistically significant. Branch length was not found to be a significant source of variation nor was the upper and lower radius of the branch.

Vessel proportion decreased considerably from the pith outwards in the stem and branches (Fig. 3). A similar trend was observed in mature wood (SAVINA and PERELYGIN 1936, KUJALA 1946, OLLINMAA 1955). The higher vessel proportion in the juvenile wood is due to the greater number of vessels present per unit area near the pith region (OLLINMAA 1955, BHAT and KÄRKKÄINEN 1981). It is evident that the increase in fibre volume from the pith outwards might explain the radial increase in basic density from the pith to the surface. The negative correlation of basic density with the frequency and percentage of vessels has been reported in birch (WALLDEN 1934, BHAT and KÄRKKÄINEN 1981) and sweetgum species (EZELL 1979).



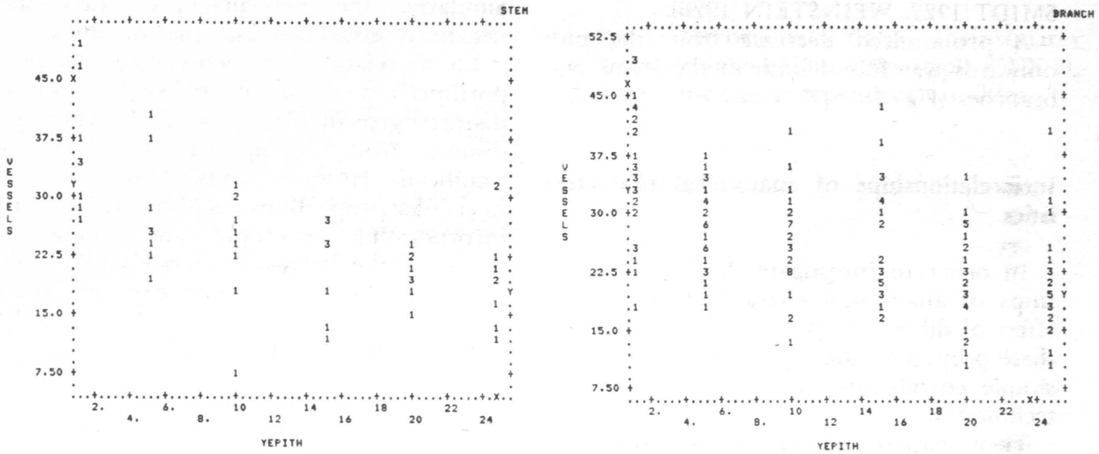


Fig. 3. Vessel proportion according to the number of growth rings from the pith in the stems (left) and branches (right).
*Kuva 3. Putkiloiden osuus ytimestä lasketun vuosilustomäärän mukaan rungoissa (vasemmalla) ja oksissa (oikealla).*

## Proportion of parenchyma

The parenchyma cells measured in this study were mainly in the rays because of the negligible volume of longitudinal parenchyma.

Ray percentage did not show any significant variation either within the stems or within the branches. However, there was a small trend of increase from the butt to the crown of the tree and a slight decrease in the branch from the base to the tip. Similar observations have been made for other hardwood species (JACCARD 1915, DE

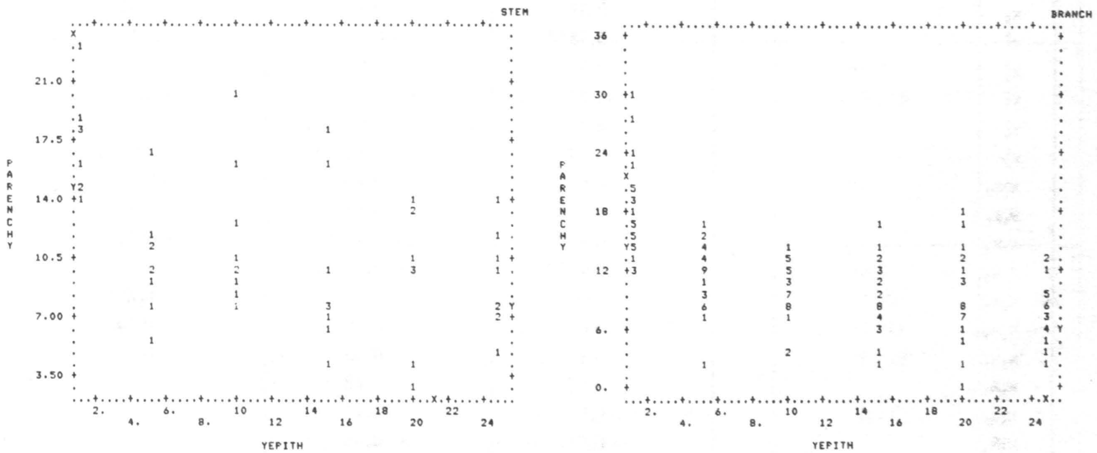


Fig. 4. Parenchyma proportion according to the number of growth rings from the pith in the stems (left) and branches (right).
*Kuva 4. Parenkyymisolujen osuus ytimestä lasketun vuosilustomäärän mukaan rungoissa (vasemmalla) ja oksissa (oikealla).*

SMIDT 1922, WEINSTEIN 1926).

A pronounced decrease from the pith outwards was found both in the stems and branches (Fig. 4).

**Interrelationships of anatomical characteristics**

In order to investigate the interrelationships of anatomical characteristics and the effect of different factors on the variation of these properties, the results were analysed by simple correlation and multiple regression techniques.

There existed a strong negative correlation between the percentage of fibres and vessels both in the stems and in the branches. Similarly, the percentage of rays was negatively associated with that of fibres.

Linear relationships between cellular proportions and certain factors like growth rate, diameter growth, height level in the trunk and distance from the branch base were not significant. However, considerable variation in cellular proportions could be explained by incorporating quadratic and interaction terms in the regression models. The best equations obtained by stepwise regression are presented in tables 5 and 6. The variables used for the analysis are as follows.

Table 4. Correlation coefficients of the branchwood.
*Taulukko 4. Oksapuun korrelaatiokertoimet.*

| Independent variable *Selittävä muuttuja* | Dependent variable *Selitettävä muuttuja* | | |
|---|---|---|---|
| | Proportion of fibres *Kuitujen osuus* | Proportion of vessels *Putkiloiden osuus* | Proportion of parenchyma *Parenkyymin osuus* |
| $x_1$ | 0,67** | – 0,55** | – 0,59** |
| $x_2$ | – 0,02 | – 0,07 | 0,19 |
| $x_3$ | 0,11 | – 0,08 | – 0,08 |
| $x_4$ | 0,01 | – 0,06 | 0,08 |
| $x_5$ | – 0,08 | 0,13 | – 0,04 |
| $x_1^2$ | 0,58** | – 0,49** | – 0,49** |
| $x_2^2$ | 0,01 | – 0,09 | 0,13 |
| $x_3^2$ | 0,13 | – 0,09 | – 0,08 |
| $x_4^2$ | – 0,00 | – 0,04 | 0,07 |
| $x_5^2$ | – 0,09 | 0,14 | – 0,04 |
| $x_1x_2$ | 0,44** | – 0,40** | – 0,31* |
| $x_1x_3$ | 0,69** | – 0,58** | – 0,58** |
| $x_1x_4$ | 0,48** | – 0,40** | – 0,41** |
| $x_1x_5$ | 0,42** | – 0,28* | – 0,48** |
| $x_2x_3$ | – 0,01 | – 0,10 | 0,22* |
| $x_2x_4$ | 0,00 | – 0,09 | 0,15 |
| $x_2x_5$ | – 0,10 | 0,06 | 0,11 |
| $x_3x_4$ | 0,07 | – 0,12 | 0,05 |
| $x_3x_5$ | – 0,07 | 0,11 | – 0,04 |
| $x_4x_5$ | – 0,07 | 0,08 | 0,00 |

* Significant at 5 % probability level
*Merkitsevä 5 % tasolla.*

** Significant at 1 % probability level
*Merkitsevä 1 % tasolla.*



Variables – *Muuttujat*

Y (1) = Fibre percentage – *Kuituja, %*
Y (2) = Vessel percentage – *Putkiloita, %*
Y (3) = Parenchyma percentage – *Parenkyymisoluja, %*
X (1) = Number of rings (age) from pith – *Ikä a ytimestä (vuosilustojen lukumäärä)*
X (2) = Ring width (growth rate), mm – *Vuosilustojen paksuus, mm*
X (3) = Height level in the trunk, m – *Korkeus maasta rungossa, m*
X (4) = Sampling disc diameter, mm – *Näytekiekon läpimitta, mm*
X (5) = Distance from branch base, m – *Etäisyys oksan tyvestä oksassa, m*

Besides the original variables, their squares and simple interaction terms (type X(1)X(2), etc) were used as independent variables.

Table 5. Regression equations for fibre, vessel and parenchyma percentage in the stemwood of *Betula pendula*.
*Taulukko 5. Regressioyhtälöt kuitujen, putkiloiden ja parenkyymisolujen osuuden (%) ennustamiseksi rauduskoivun runkopuussa.*

| Dependent variable *Selitettävä tekijä* | Independent variable *Selittävä tekijä* | Coefficient *Kerroin* | t-value *t-arvo* |
|---|---|---|---|
| Fibre percentage *Kuituja, %* | Constant – *Vakio* | 53,9 | |
| | Years from the pith x disk diameter, mm *Vuosilustoja ytimestä x kiekon läpimitta, mm* | 0,004 | 6,4 |
| | $R^2$ = 43,9 % | | |
| | F = 41 (1,52) | | |
| | $s_{y.x}$ = 8,3 | | |
| Vessel percentage *Putkiloita, %* | Constant – *Vakio* | 32,0 | |
| | Years rom the pith x disk diameter, mm *Vuosilustoja ytimestä x kiekon läpimitta, mm* | – 0,003 | 5,6 |
| | $R^2$ = 37,5 % | | |
| | F = 31 (1,52) | | |
| | $s_{y.x}$ = 6,6 | | |
| Parenchyma percentage *Parenkyymisoluja, %* | Constant – *Vakio* | 16,0 | |
| | Years from the pith – *Vuosilustoja ytimestä* | – 1,09 | 5,3 |
| | Years from the pith squared – *Edellisen neliö* | 0,026 | 3,5 |
| | Years from the pith x ring width, mm *Vuosilustoja ytimestä x vuosiluston leveys, mm* | 0,123 | 2,2 |
| | Ring width (mm) x distance from the ground (m) *Vuosiluston paksuus (mm) x etäisyys maasta (m)* | 0,147 | 3,3 |
| | $R^2$ = 56,3 % | | |
| | F = 16 (4,49) | | |
| | $s_{y.x}$ = 3,1 | | |

Table 6. Regression equations for fibre, vessel and parenchyma percentage in the branches of *Betula pendula*.
*Taulukko 6. Regressioyhtälöt kuitujen, putkiloiden ja parenkyymisolujen osuuden (%) ennustamiseksi rauduskoivun oksissa.*

| Dependent variable *Selitettävä tekijä* | Independent variable *Selittävä tekijä* | Coefficient *Kerroin* | t-value *t-arvo* |
|---|---|---|---|
| Fibre percentage *Kuituja*, % | Constant – *Vakio* | 40,7 | |
| | Ring width, mm – *Vuosiluston leveys, mm* | 9,40 | 6,3 |
| | Years from the pith, squared *Vuosilustoja ytimestä, neliö* | – 0,049 | 6,4 |
| | Years from the pith x distance from the ground, m – *Vuosilustoja ytimestä x etäisyys maasta, m* | 0,140 | 10,9 |
| | $R^2 = 61,5$ % | | |
| | F = 92 (3,172) | | |
| | $s_{y.x} = 6,6$ | | |
| Vessel percentage *Putkiloita*, % | Constant – *Vakio* | 43,1 | |
| | Years from the pith, squared *Vuosilustoja ytimestä, neliö* | 0,029 | 4,6 |
| | Years from the pith x distance from the ground, m – *Vuosilustoja ytimestä x etäisyys maasta, m* | – 0,088 | 8,3 |
| | Ring width (mm) x distance from the ground (m)– *Vuosiluston leveys (mm) x etäisyys maasta (m)* | – 0,676 | 6,6 |
| | $R^2 = 49,4$ % | | |
| | F = 56 (3,172) | | |
| | $s_{y.x} = 5,8$ | | |
| Parenchyma percentage *Parenkyymisoluja*, % | Constant – *Vakio* | 17,5 | |
| | Years from the pith – *Vuosilustoja ytimestä* | – 0,909 | 7,3 |
| | Years from the pith squared – *Edell. neliö* | 0,025 | 5,4 |
| | Years from the pith x distance from the branch base, cm – *Vuosilustoja ytimestä x etäisyys oksan tyveltä, cm* | – 0,001 | 2,6 |
| | $R^2 = 47,2$ % | | |
| | F = 51 (3,172) | | |
| | $s_{y.x} = 3,4$ | | |

## CONCLUSION

The results indicate that there are no significant differences in the cellular proportions between the branch wood and stem formed wood of the juvenile stage when the same growth rings counted from the pith are compared. On the contrary, there is a difference between the crown formed wood and stem formed wood; the proportion of fibres is higher and the proportion of vessels lower in the latter. Both in the stem and in the branches there is an increase in the proportion of fibres and a decrease in the vessels and rays from the pith to the surface.



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*SELOSTE:*

*SUOMALAISEN KOIVUPUUN RAKENTEEN JA ERÄIDEN OMINAISUUKSIEN VAIHTELU III. RAUDUSKOIVUN RUNGON JA OKSIEN SOLULAJIEN RUNSAUSSUHTEET*

Neljästä rauduskoivurungosta tutkittiin, mikä oli eri solulajien osuus rungon ja oksien poikkipinta-alasta. Kun tarkasteltiin samalla etäisyydellä ytimestä olevaa vuosilustoa, havaittiin, että kuitujen osuus aleni rinnantasalta latvukseen ja sieltä lisääntyi oksiin. Päinvastainen trendi oli havaittavissa putkiloissa ja parenkyymisoluissa, joiden osuus käytännössä oli samaa kuin ydinsädesolujen osuus.

Sekä rungossa että oksissa kuitujen osuus kasvoi ytimestä pintaan päin ja putkiloiden sekä parenkyymisolujen osuus aleni. Tällainen muutos vahvistaa käsitystä, että kuivatuoretiheyden kasvu ytimestä pintaan päin johtuu pääasiassa kuitujen osuuden kasvamisesta.

Solulajien runsaussuhteiden vaihtelua tutkittaessa pystyttiin regressiomallilla selittämään kuitujen osuuden vaihtelusta rungossa 49 % ja oksissa 61 %. Vastaavasti putkiloiden osuuden vaihtelusta pystyttiin selittämään 37 % rungossa ja 49 % oksissa. Vastaavat luvut parenkyymisolujen osuudelle olivat 56 ja 47 %. Parhaat selittävät tekijät koskivat ytimestä vuosilustoina mitattua etäisyyttä, tarkastelukohdan korkeutta maan pinnasta sekä kasvunopeutta.