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THE IMPACT OF SILVICULTURAL TREATMENTS ON THE STRUCTURE AND RED HEART FORMATION IN BEECH FORESTS

UTJECAJ ŠUMSKOUZGOJNIH ZAHVATA NA STRUKTURU I FORMIRANJE NEPRAVE SRŽI U BUKOVIM SASTOJINAMA

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ABSTRACT: The issue of occurrence and size of red heart and the possibilities of its limitation in beech assortments have been researched in worldwide measures for a long time. There are many ecological, phenological, geological factors which more or less influence its formation. The results of a long-term research of different silvicultural treatment confirmed that a big crown of crop trees creates conditions to achieve the target diameter with a low assumption of red heart formation and so rises the quality and price of produced assortments. The different shaping of tree crowns on two investigated compartments had a significant impact on the size of dehydrated zone and subsequently on the frequency of red heart. On the contrary, it did not have a significant impact on the size of red heart, even though red hearts in the both investigated forest stands were small. We also found the different qualitative structure of assortments in both types of investigated compartments.

Key words: Fagus sylvatica *L., silvicultural methods, red heart formation, sapwood, dehydrated zone*

INTRODUCTION – Uvod

Red heart (RH) and growth stresses appearing in beech species are the main phenomena which influence the quality of raw wood and so they decrease significantly the financial value of the produced range of raw wood (Becker et al. 2005). The topic of RH formation in beech wood species has been the subject of the research for long. There were published many extensive monographs and papers about the structure, formation, and development of red heart from the viewpoint of physiology, macroscopic and microscopic changes of beech wood (Bosshard 1967, 1968, Hösli and Bosshard 1975, Koch et al. 2003, Necesany 1958, 1969, 1973a, 1973b, Sachsse 1991, Schmidt and Mehringer 1989, Sorz and Hietz 2008, Torelli 1984, Torelli 2001, Zycha 1948) etc.

Findings from the specialized literature point out that beech RH is subjected by, in fact, two main factors: formation of the dehydrated zone (DZ) and by entering of air into this zone (Bosshard 1974, Torelli 1984, Torelli 2001, Zycha 1948). The absence of one of these factors excludes formation of RH. Decreasing of vitality the parenchyma cells and breaking down of the water transport system in central part of a stem is a consequence of decreasing physiological activity of tree, impacted mainly by ageing. This central DZ is also called as a ripe or mature wood. Water/gaz ratio in the vessels of DZ is important for a potential RH formation (Sachsse 1967, Torelli 1984). The wound of a trunk and branches causes that air enters into vessel system of sapwood (SW) and DZ. The penetration rate of air into the zones SW and DZ has different partial pressures in the stem and the atmosphere (Bosshard 1967, Ziegler 1968). The relatively vital parenchyma cells (adja-

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cennt to vessels) react to the embolism by plugging the vessels with tyloses (Zycha 1948, Necesany 1958, Bonsen and Kucera 1990). Simultaneously, oxidative reactions transtorm the starch and soluble carbohydrates in living cells into coloured phenol substances. Subsequently, coloured phenol compounds form parenchyma cells are deposited in the surrounding xylem (Bauch and Koch 2001). RH formation will terminate when the wound is closed. An important factor in this process is the closure rate of injuries to new growth rings of wound wood (Shigo and Larson 1969).

The RH formation (frequency and size) from a macroscopic view is significantly influenced by the age, diameter at breast height (DBH) of stem (Knoke and Wenderoth 2001, Krempl and Mark 1962, Mahler and Höwecke 1991, Racz et al. 1961, Walter and Kucera 1991), the occurrence of injury (Büren 1998, Keller 1962, Kucera 1991, Raunecker 1956, Wernsdörfer et al. 2005), crown size and sociological status of the tree in a forest stand (Chovanec 1974, Torelli 1984, Vasilievič 1974), forest soil and geological bedrock (Büren 1998, Furst et al. 2006, Schmidt et al. 2005) etc.

Recently, a lot of authors have been dealing with an assessment of forest stand quality impact and the impact of tending and regeneration silvicultural methods on the log quality from the viewpoint of the RH frequency (Kadunc 2006, Knoke 2003, Kudra et al. 2003, Prka 2003, Schmidt et al. 2005). The knowledge that generally applies is that in case of formation and frequency of RH, forest stand age, trunk diameter and also in some cases, group of forest types (Mahler and Höwecke 1991) are of a significant importance. Sustaining the whole section of beech trunk in an active profile depends on the capacity of its crown. Considering the value production of beech wood, the lower third of a trunk is preferred. This part represents 90% of its value production. This knowledge is used during intensive crown thinning focusing on bigger target diameter which is then achieved considerably sooner. The intensive crown thinning has an impact on lower frequency of RH occurrence in case when we accept the target diameter of 40–50 cm (Kadunc 2006, Kudra et al. 2003). Silvicultural methods which create large growth space for crop trees and so the shorter time to achieve thick dimensions decrease the risk of wood devaluation by RH (Knoke 2002, Knoke and Wenderoth 2001).

As mentioned above, there are a lot of factors influencing formation and dynamics of development of RH in beech stands. The aim of the paper is to evaluate the impact of two silvicultural techniques which create different conditions for crown development, RH occurrence in homogenous beech forest stands, while other factors (soil type, stand origin, slope aspect, altitude, etc.) are the same.

MATERIALS AND METHODS – Materijali i Metode

To verify the stated aim sample trees of beech were chosen and processed. To maximize the elimination of other factors the sample trees were chosen from two compartments (CMTs) placed next to each other when each of them was cultivated by a different silvicultural technique. The forest stands belong into the Forestry Enterprise of the Technical University in Zvolen and have been monitored in detail for research purposes for 30–45 years by the employees of the Department of Silviculture at the Forestry Faculty in Zvolen.

In the CMT 513 were set up two sample permanent plots (SPPs) in 1980. In the CMT has been used quality crown thinning up to 1980. In 1986 and 1991 there was done selective thinning, from 1991 to 2009 there was done selection cutting twice with the volume of 70–80 m^3/ha.

The CMT 514b is located next to the CMT 513. It has the same parameters group of forest types. The CMT 514b presents a set of four SPPs which have been cultivated by crown thinning with a positive selection since 1966 focusing on maximal release of crowns of future crop trees. Before every thinning since that time there were done measurements of selected dendrometric parameters. The relative thinning weight in the thinning interval of 5 years up to 1991 was at 16–18%. In the 1991 the last release increment thinning was done with the volume 24–26% from the forest stand.

The altitude of the both CMTs is 510–540 m, the slope aspect is south-west, slope declination 20–25%, and geological parent rock is andesite, soil type Cambisoil, group of forest types: *Fagetum pauper*. Dendrometric parameters were measured in 1986, 1991, 1997, 2001, and 2009. From two CMTs there were chosen 14 dominant trees (7+7 trees from each CMT), in the age of 93–112 years. The crown volume of selected trees (C_k) was calculated according to (Jurča 1968)

$$C_k = (\pi/8) \times b^2 \times l \qquad (1)$$

where *b* is the crown width and *l* is the crown length in meter. The final dendrometric parameters are in the Table 1.

Table 1 Basic dendrometric characteristics of beech sample trees from the individual SPPs.
Tablica 1. Osnovne dendrometrijske značajke reprezentativnih bukovih stabala na trajnim istraživačkim plohama (SPPs)

CMT *Odjeli*	Tree *Stablo*	Tree age at DBH *Dob stabla na prsnom promjeru*	DBH *Prsni promjer*	Tree height *Visina stabla*	Crown width *Širina krošnje*	Crown length *Duljina krošnje*	Crown volume *Volumen krošnje*
	No	(year)	(cm)	(m)	(m)	(m)	(m^3)
513	75	112	47.2	30.9	9.8	20.3	765.2
513	190	108	49.8	30.5	10.75	13.9	630.5
513	85	111	47.6	29.3	10.45	12.1	518.6
513	41	108	55.6	33.3	12.7	25.3	1601.7
513	120	110	43.2	31.6	9.1	17.2	559.1
513	154	111	45.7	29.6	8.5	14.3	405.5
513	19	108	46.4	28.5	9.65	16.8	614.0
514b	15	103	53.9	34.0	12,15	24.2	1402.2
514b	33	98	38.0	28.1	8.8	18.2	553.2
514b	21	98	40.3	28.8	10	19.8	777.2
514b	30	102	49.6	30.6	10.5	19.1	826.5
514b	42	96	39.4	27.6	7.1	12.8	253.3
514b	37	94	43.0	29.5	9.95	17.4	676.1
514b	3	93	42.7	27.9	9.35	16.8	576.5

The data were measured on standing trees before cutting in December 2009
Podaci su uzimani na dubećim stablima prije sječe u prosincu 2009. godine

The marked trees were cut, delimbed, bucked into 12–14 m transportation lengths and transported into the forest depot. The sample removal was carried out during bucking of logs according to the scheme on Fig. 1.

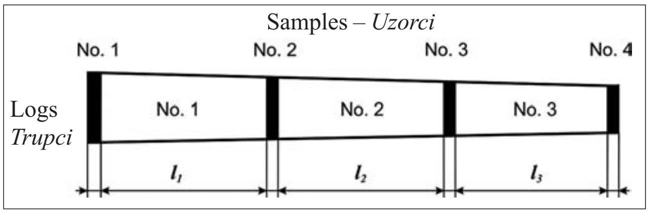

Figure 1 Cutting scheme of samples. Variable log length (l1, l2…ln) depended on quality assessment
Slika 1. Shema prereza uzoraka. Duljina trupca (l1, l2,...ln) ovisna o procijenjenoj kvaliteti sortimenta

In total there was taken 60 samples, out of which 10 samples contained RH + DZ (Fig. 2a) and 50 samples contained only DZ (Fig. 2b). The first sample type was cut from the butt part. The position of the other sample types in a trunk depended on the length of bucked logs and it moved depending on the stated quality of logs within 2–6 m. The position (distance) of every sample and every log from the butt was recorded in meters. The quality of every log according to (STN EN 1316-1 2000) was stated.

In half an hour after cutting the sample, a visible dry DZ appeared on the cross section of the sample. The samples were planed from one side and photographed in the JPG format of 24-bit RGB in resolution 1536 x 1024 pix, 300dpi (Fig. 2).

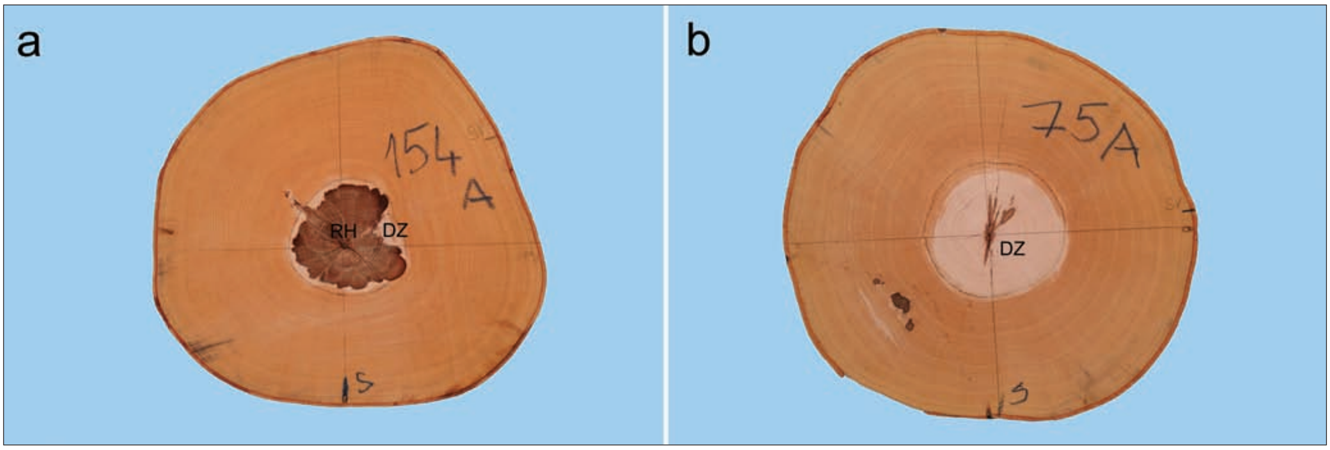

Figure 2 Cross section of samples (a) – the samples containing both zones (RH and DZ) (b) – the samples containing only DZ
Slika 2. Poprečni prerez uzoraka (kolut) (a) – uzorci koji imaju nepravu srž (RH) i piravost (DZ). (b) – uzorci koji imaju samo piravost (DZ)

The diameter of samples and the width of the DZ and RH were measured. At the same time, the age of the tree at DBH and at other heights and the cambial age (CA) of the trunk were counted. The ratio of DZ to RH was calculated as ratio of DZ width or RH and diameter of the trunk as a percentage.

RESULTS – Resultati

The analysis of the Table 1 and Table 2 points out that the DBH structure of tree samples for a different silviculture technology is different. In case of the CMT 513, the DBH are statistically significantly bigger than CMT 514 b. In CMT 513, where trees of an upper level are autonomous in growth during practically whole observation time, creates assumptions of more intensive diameter growth. Moreover, it is necessary to add to this fact partially the factor of age, whereas observed samples are approximately 10 years older. The sample trees, obtained from the CMT 513, have, at partially different age, higher parameters of the DBH and volumes of the down third of a trunk. Higher parameters of quantitative production are the result of a considerably higher capacity of assimilation apparatus of a crown. The analysis of production parameters of beech samples confirmed, despite their partially different age, that selection structure of a stand creates significantly good qualitative assumptions for its quantitative and value production.

Table 2 T-tests of mean values of tree characteristics for investigated CMTs.
Tablica 2. T-test srednjih vrijednosti značajki stabala istraživanih sastojina (CMTs)

CMT *Odjeli*	Tree age *Dob stabala*	p-value *p vrijednost*	DBH *Prsni promjer*	p-value *p vrijednost*	Crown length *Duljina krošnje*	p-value *p vrijednost*
513 514b	109.7±1.58 97.7±3.51	0.0001***	47.9±3.63 43.8±5.38	0.0494*	17.1±4.15 18.3±3.18	0.5846ns

Mean values (within the same column mean ± standard deviation (SD)) were calculated based on measurements taken in december 2009. Student´s t-test (p-value – level of statistical significance, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$, ns - not statistically significant, $p > 0.05$).
Srednje vrijednosti (u istoj koloni dane su srednje vrijednosti i standardna devijacija) temeljem mjerenja iz prosinca 2009. godine. Student-ov t-test (p-vrijednost – stupanj statistički značajne razlike – ns nije statistički značeno).

Table 3 Comparison of crown volumes C_k (m^3) development during the last 23 years for investigated CMTs
Tablica 3. Usporedba volumena krošanja C_k (m^3) tijekom 23 godine motrenja na istraživanim plohama CMTs

CMT *Odjeli*	1986		1991		1997		2001		2009	
	C_k	p-value *p vrijednost*	C_k	p-value *p vrijednost*	C_k	p-value *p vrijednost*	C_k	p-value *p vrijednost*	C_k	p-value *p vrijednost*
513 514b	297±133 175± 69	0.0432*	391±156 197± 74	0.0328*	582±234 357±188	0.0087**	624±266 386±145	0.0432*	727±401 723±353	0.9812ns

Within the same column (mean ± SD). Student´s t-test (p-value – level of statistical significance, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$, ns (not statistically significant, $p > 0.05$).
U istoj koloni dane su srednje vrijednosti i standardna devijacija. Student-ov t-test (p-vrijednost – stupanj statistički značajne razlike – ns nije statistički značeno).

The average crown volumes for individual CMTs during the past 23 years significantly differed, with the exception of the last growth period 2001–2009. The average crown volumes (in the years 1986–2001) in the CMT 513 was about 23–35% higher, than in the CMT 514b (Table 3).

The analysis of correlation strength between tree samples DBH and their height for the whole period of observation (23 years) is characterized in the Fig. 3a, 3b.

While we are assessing this dependency on CMT 513 (Fig. 3a), determination coefficient has a significantly higher value, i. e. in case of growth relations between the diameter and the height of sample trees there is a stronger dependency.

The analysis of the relationship between the volume of a crown and the DBH of beech sample trees is interesting. In case of the sample trees from the CMT 513 the determination coefficient is significantly lower than for sample trees from the CMT 514b, which were cultivated by crown thinning with a positive selection (Fig. 4a, 4b).

The mentioned fact confirmed that beech sample trees in the stand cultivated by crown (increment) thinning with the support of crop trees take up to 68% impact on diameter growth of a trunk. On the other hand, crown of beech sample trees which are in the upper layer of selection forest in a autonomous position for a long time have determination coefficient $R^2= 0.453$, i. e. the capacity of a crown takes only 45% impact on a diame-

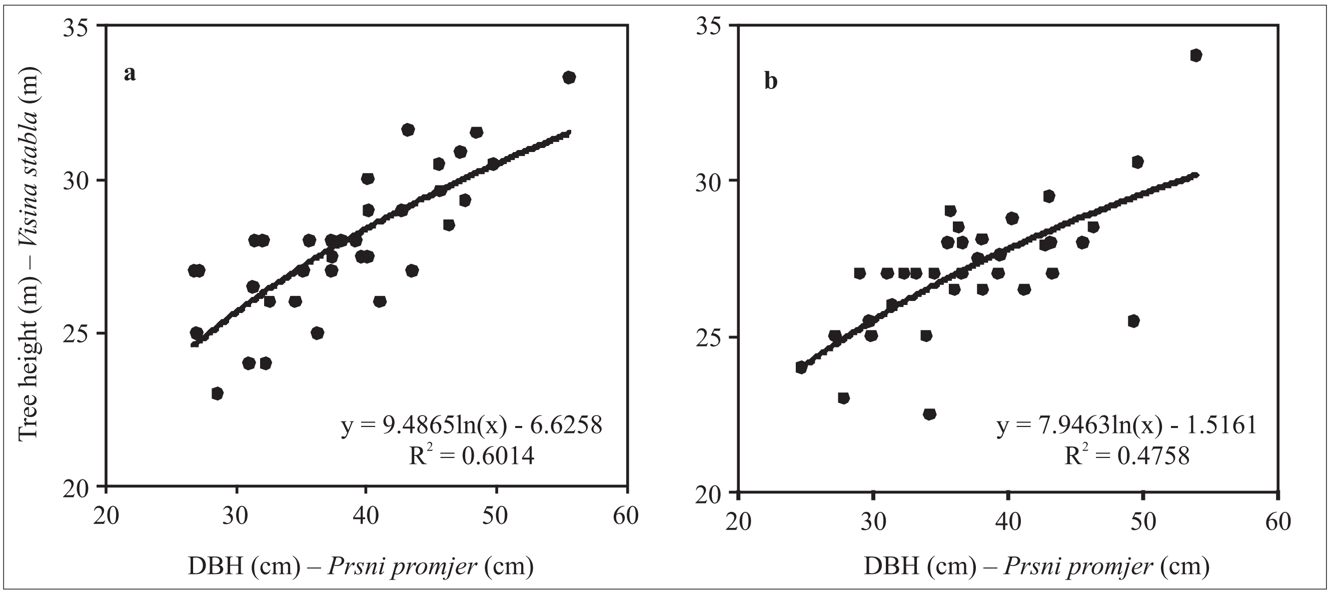

Figure 3 Dependency of the tree height on DBH. (a) – CMT 513 with a selection structure, (b) – CMT 514b with release increment thinning
Slika 3. Ovisnost visine stabla o prsnom promjeru (DBH). (a) – CMT 513 preborna struktura sastojine, (b) – CMT 514b sastojina njegovana visokom proredom

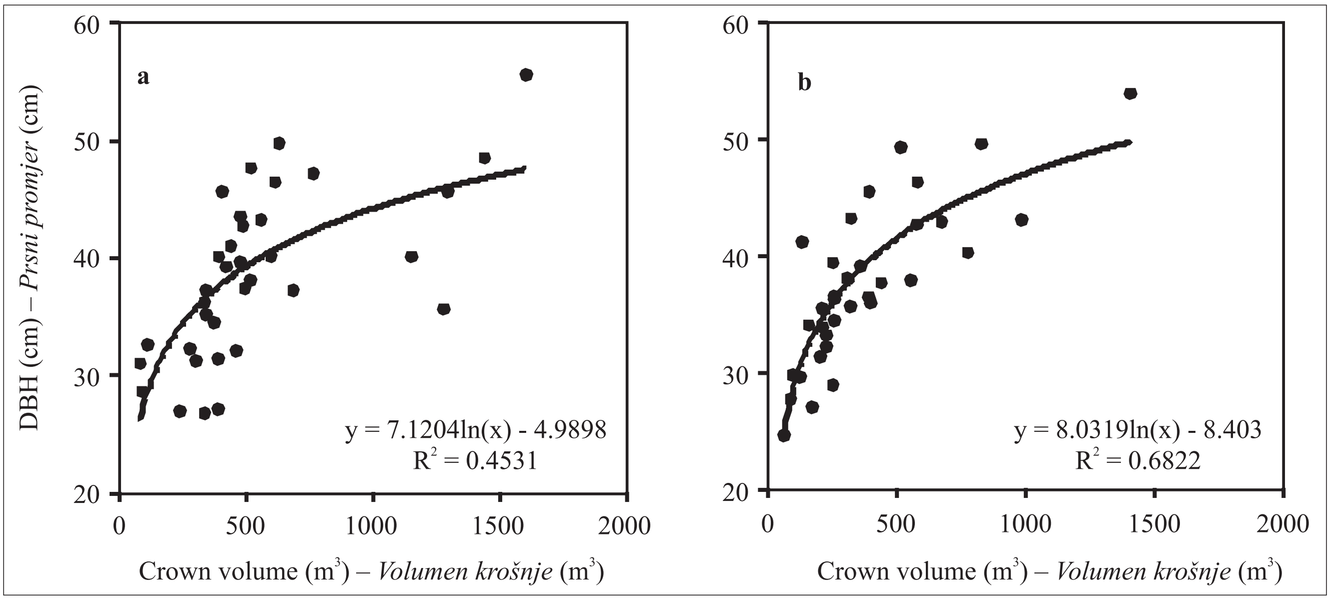

Figure 4 Dependency of DBH on crown volume. (a) – CMT 513 with a selection structure, (b) – CMT 514b with release increment thinning
Slika 4. Ovisnost prsnog promjera (DBH) i volumena krošnje na uzorkovanim stablima. (a) - CMT 513 preborna struktura sastojine, (b) – CMT 514b sastojina njegovana visokom proredom

ter growth of a tree trunk. This significant finding proves the fact that there are more than 55% of other factors not considered by us which take an impact on the increment of sample trees at DBH in a selection forest.

From the point of view of RH occurrence we can see (Fig. 5) that its frequency in trees and logs coming from CMT 513 is considerably lower than the frequency in the CMT 514b.

On contrary, the influence of various ways of forest stand tending on portion of RH was not proved as sta-

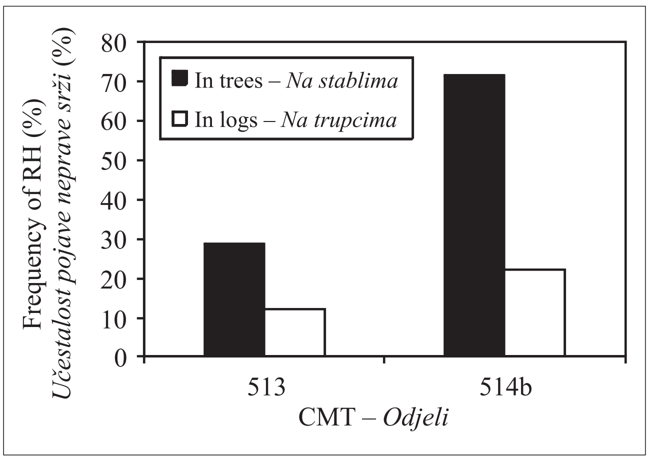

Figure 5 Frequency of RH in trees and logs for individual CMTs
Slika 5. Frekvencija pojavnosti neprave srži (RH) na stablima i trupcima na istraživanim plohama (CMTs)

tistically significant, but average values in both observed CMTs were considerably low (Table 4).

From the viewpoint of the size of created zone of DZ expressed by its diameter proportion we can assume that considering higher age of the trees from CMT 513 (109.7 years) the portion of DZ compared to the CMT 514b (97.7 years) should be higher. But the results present an opposite trend. (Table 2, Table 4).

Table 4 T-tests of mean values of DZ portion (%) and RH portion (%) for investigated CMTs

Tablica 4. T-test srednjih vrijednosti postotnog udjela piravosti (DZ) i neprave srži (RH) na istraživanim plohama (CMTs)

CMT – *Odjeli*	DZ portion – *DZ udjel*	p-value – *p vrijednost*	RH portion – *RH udjel*	p-value – *p vrijednost*
513	19.4±6.67	0.0097**	11.7±3.76	0.5806ns
514b	23.9±6.49		10.3±3.96	

Within the same column (mean ± SD). Student´s t-test (p-value – level of statistical significance, *p < 0.05, **p < 0.01, ***p < 0.001, ns (not statistically significant, p > 0.05).

U istoj koloni dane su srednje vrijednosti i standardna devijacija. Student-ov t-test (p-vrijednost – stupanj statistički značajne razlike – ns nije statistički značeno).

Table 5 Linear regression dependences between DZ or SW width (cm) and CA (year) or H in trunk (m) for investigated CMTs.

Tablica 5. Linearna regresija ovisnosti širine piravosti, odnosno bijelji (SW) izražena u cm s kambialnom starosti debla (CA) (godina) ili visinom debla (H) za istraživane plohe (CMTs)

Dependency – *Ovisnost* y = a + b.x (y × x)	CMT – *Odjeli 513*				CMT – *Odjeli 514b*			
	a	b	R	p-value *p vrijednost*	a	b	R	p-value *p vrijednost*
DZ width × CA in trunk *DZ širina × CA debla*	-3.571	0.1193	0.6352	0.0000***	-0.164	0.105	0.5794	0.0015**
DZ width × H in trunk *DZ širina × H debla*	9.702	-0.279	0.5736	0.0005***	10.746	-0.332	0.6108	0.0007***
SW width × CA in trunk *SW širina × CA debla*	9.777	0.221	0.5942	0.0002***	3.782	0.281	0.6962	0.0000***
SW width × H in trunk *SW širina × H debla*	35.145	-0.612	0.6367	0.0000***	31.728	-0.689	0.5665	0.0020**

H – height in trunk (m) from bottom of tree; a – absolute coefficient, b – regression coefficient, R – correlation coefficient, p-value – level of statistical significance correlation coeficient *p < 0.05, **p < 0.01, ***p < 0.001, ns (not statistically significant, p > 0.05), y – dependent variable, × – independent variable

*H – visina debla (m); a – apsolutni koeficijent, b – regresijski koeficijent, R – korelacijski koficijent, p-vrijednost – stupanj statistički značajne razlike korelacijskog koeficijenta *p < 0.05, **p < 0.01, ***p < 0.001, ns (nije statistički značajno, p > 0.05), y – zavisna varijabla, × – nezavisna varijabla*

Table 6 The vertical distribution and position of the RH in trunk. RHL (m) means RH length at the specified position in trunk.

Tablica 6. Vertikalno rasprostiranje neprave srži (RH) u deblu stabla. RHL (m) označava visinu do koje se rasprostire neprava srž (RH)

CMT *Odjeli*	Tree *Stablo* No.	RHL *Visina do koje se rasprostire neprava srž*
513	154	0 - 5
513	85	6 – 8 and 23 – 24
514b	42	0 – 2
514b	3	0 – 5
514b	37	0 – 7 and 14 – 16
514b	15	1 – 6
514b	33	8 – 11

Between the width of DZ or SW and CA of a trunk there were found increasing linear regression dependences with relatively high correlation coefficients (Table 5). The given fact points out at the relatively strong influence of age on DZ and SW formation.

Table 6 presents distribution and position of RH along the trunk length. It can be clearly seen that RH in most trees in both forest stands occurs in 0-8m distance from the butt. Therefore, the wound, which was a cause of such RH formation, occurred at tree butts and was caused by a wound of butt parts. For the sample trees No. 85 (CMT 513) and No. 33 and 37 (CMT 514b) the wound was caused by dieback of thick branches of yet standing trees in the lower parts of the crowns.

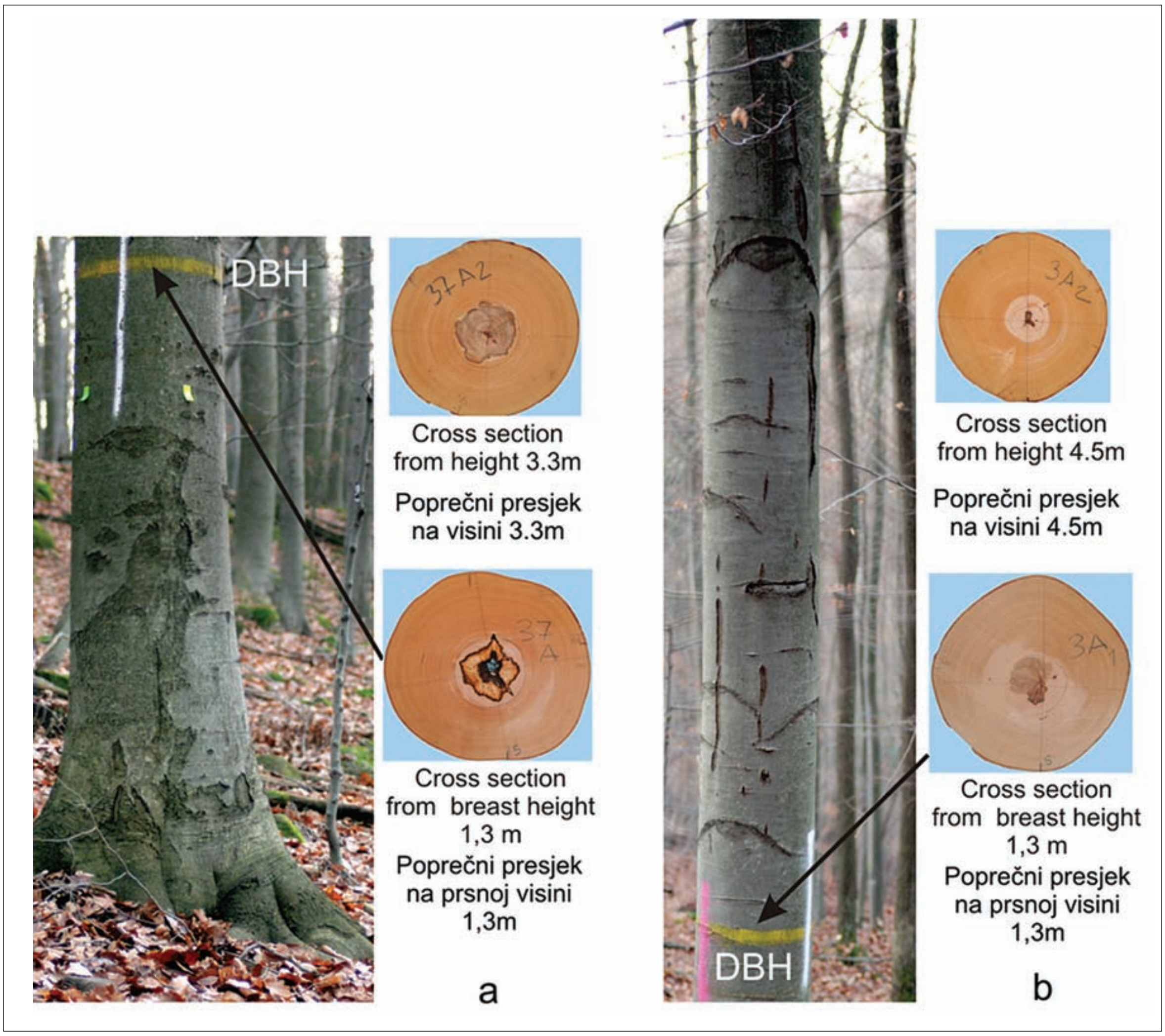

Figure 6 Surface wounds in the bottom of the trunk documenting their relation to RH formation. (a) – large injury (tree no.37) lead to expansion of RH up to 7m and decay up to 2 m. (b) – small injuries (tree no.3) did not affect the RH formation. The RH have been formed in height of 0 to 5 m from a larger branch in 2.8 m height.

Slika 6. Dokumentacija utjecaja oštećenja žilišta na formiranje neprave srži (RH). (a) – Veliko oštećenje (stablo br. 37) dovelo je do širenja neprave srži (RH) do visine od 7 m i truleži do 2 m. (b) – Malo oštećenje (stablo br. 3) nije imalo utjecaja na nastanak neprave srži (RH). Pri tome je neprava srž na visini od 0 do 5 m bila formirana zbog velike grane na visini od 2,8 m.

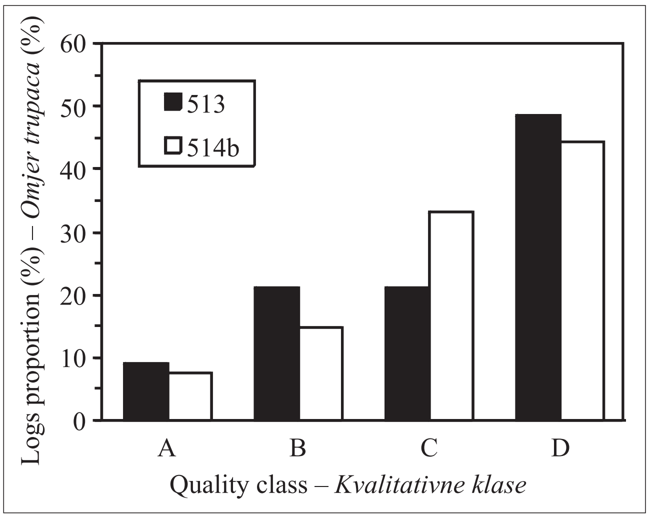

Figure 7 Quality structure of logs from individual CMTs

Slika 7. Kvalitativna struktura prereza sa istraživačkih ploha CMTs

Different qualitative structure of produced assortments coming from the observed forest stands, which contained RH at least at one of the cross sections, can be seen at Fig. 7. The analysis of quality of produced logs confirmed that the higher quality and so the value yield was achieved for the assortments coming from the CMT 513. Significantly higher portion of logs was achieved in quality classes A and B. Compared to this, there was a considerably lower proportion of logs in class C.

DISCUSSION – Rasprava

To start with, it is necessary to remember that the analyzed experiment is based on the exact data on change dynamics of chosen dendrometric parameters of chosen trees of the same ecotype in the same ecological and geological conditions with a different silviculture technique. Homogenization of ecological and geological conditions creates assumptions to find a relatively clear answer to the questions on the influence of different silviculture techniques on the formation of RH for beech.

The results confirmed that autonomous and long-term position of beech trees with the crown length longer than a half of a tree height in the upper layer of selection system forest (CMT 513) creates conditions to achieve target DBH of 45–50cm (age 100–110 years) with a very low assumption of RH formation.

Similar results were achieved in case of crown thinning with a positive selection (CMT 514b) and grading its relative thinning strength to 24–26% of the taken volume capacity of beech stand in the age of 80 years. To achieve target beech diameter in the age of 100–110 years it is necessary to form its crown according to the above mentioned parameters (Mahler and Höwecke 1991). By this way the assumptions are created for fully functional activity of the whole section of a trunk. The found parameters correspond with the requirements of Bachmann (1990) for quality forming of the lower third of a trunk which in case of beech presents 60% of its volume and up to 90% of its value production.

The achieved results about frequency of RH confirmed that we can help to decrease it by the different way of silviculture treatment. Especially the selection system achieved considerably lower frequency of RH (Fig. 5). In comparison with literature (Mahler and Höwecke 1991) it was considerably lower for the same age of 100-120 years and for the trunk diameter at the DBH 40–49 cm. By Prka (2003), who investigated this issue of beech stands in a regeneration phase in the age of 100 to 110 years, the frequency of RH was approximately 50%.

The issue of the changing size of DZ (Table 4) can be understood as an important restricting factor of formation and size of RH. Therefore, a key factor of injuries on the bottom of tree was partially eliminated by a wide zone of SW. The air entering into the trunk had to overcome a bigger distance between the trunk surface and DZ. Large injuries at the bottom occurred only in a few cases (Fig. 6a), more often small wounds were closed by new formed wound wood even before air entering into DZ (Fig. 6b).

With changing CA at the different height of a trunk there appears the change of DZ width (Table 5). From the viewpoint of frequency of RH it is apparent that the RH occurred especially in the parts of trunk with higher CA and predominantly in those trees where the DZ was wider. However, we can see from the Table 6 that RH was formed in a few cases in the upper parts of trunk. Wernsdörfer et al. (2005) pointed that only some wounds and branch marks on the bark are responsible for the RH formation. Torelli (2001) defines the formation of dry central zone in the middle of a beech trunk as a dynamic process analogical towards the RH formation for other wood species, while a tree adjusts the SW size (active transpiration area) to the crown size. In general, it applies that the age has a dominant influence on ageing and dieback of parenchyma and so on the increase of DZ portion at the expense of SW (Bosshard 1965).

On the other hand, the influence of crown volume contributes to alteration of portion between SW and DZ width (Torelli 1974, 1984). Also, quality of the crown (leaves size, foliage density, ration of shadowy and lighted leaves as well as their proportional or disproportional distribution) have influence on average annual growth ring width (Assmann 1961) and transpiration flow of water through the trunk (Bartelink 1997, Deckmyn et al. 2006). This must consequently show at the higher capacity of vital parenchyma which is capable to fulfill a supplying function in a tree. However, the crown development of healthy trees should be understood as a dynamic process, which is mainly influenced by age and performed thinning activities. Different methods of thinning activities performed on investigated CMTs in the last 23 years caused that the average crown volumes (apart from the last 8 years) differed significantly (Table 3). It caused differences in final average DZ portions (Table 4).

The achieved results entitle us to assume that even in the higher age of trees it is possible to influence positively the ratio between SW and DZ by a suitable silviculture activity leading to an increase of the crown size and quality from the photosynthesis point of view and so contribute to a decrease of frequency of occurrence and size of RH. This will consequently show at the quality and price of the produced assortments.

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REFERENCES – Literatura

Assmann, E. 1961: Waldertragskunde. B.L.V., München-Bonn-Wien, Germany.

Bachmann, P. 1990: Produktionssteigerung im wald durch vermehrte berücksichtigung des wertzuwachses. Berichte - Eidgenossische Anstalt fur das Forstliche Versuchswesen. Wald Schnee Landschaft 327: 73.

Bartelink, H. 1997: Allometric relationships for biomass and leaf area of beech (*Fagus sylvatica* L.). Annals of Forest Science 54: 39–50.

Bauch, J., G. Koch 2001: Biologische und chemische untersuchungen über holzverfärbungen der rotbuche (*Fagus sylvatica* L.) und möglichkeiten vorbeugender massnahmen. Abschlussbericht, Bundesforschungsanstalt für Forst und Holzwirtschaft, Universität Hamburg, Germany.

Becker, G., U., U. Seeling, H. Wernsdörfer 2005: Relationship between silvicultural methods and beech wood quality - the German experience. Revue Forestiere Francaise 57: 227–238.

Bonsen, K. J. M., L. J. Kucera 1990: Vessel occlusions in plants – morphological, functional and evolutionary aspects. Iawa Bulletin n.s. 11: 393–399.

Bosshard, H. H. 1965: Aspects of the aging process in cambium and xylem. Holzforschung 19: 65–69.

Bosshard, H. H. 1967: Über die fakultative farbkernbildung. Holz als Roh und Werkstoff 25: 409–416.

Bosshard, H. H. 1968: On the formation of facultatively colored heartwood in *Beilschmiedia tawa*. Wood Science and Technology 2: 1–12.

Bosshard, H. H. 1974: Holzkunde. Zur biologie, physik und chemie des holzes. Biräuser Verlag 312, Basel, Switzerland.

Büren, S. v. 1998: Buchenrotkern: Erkennung, verbreitung und wirtschaftliche bedeutung. Schweizerische Zeitschrift fur Forstwesen 149: 955–970.

Deckmyn, G., S. P. Evans, T. J. Randle 2006: Refined pipe theory for mechanistic modeling of wood development. Tree Physiology 26: 703–717.

Furst, C., T. , T. Seifert, F. Makeschin 2006: Do site factors affect the wood quality of European beech (*Fagus sylvatica* L.)? Results from a pre-study on red heartwood. Forst und Holz 61: 464–468.

Hösli, J. P., H. H. Bosshard 1975: Überprufung der tränbarkeit von rotkernigen buchenholz mit steinkohleteeröl. Tränkerfolg in abhängigkeit der thylleheufigkeit. Schweizerische Zeitschrift für Forstwese 126: 965–875.

Chovanec, D. 1974: Possibilities of preventing the formation of beech heartwood. Lesnicky casopis 20: 339–354.

Jurča, J. 1968: Pěstební analytika. SPN, Praha, Czech Republic.

Kadunc, A. 2006: The quality and value of European beech roundwood (*Fagus sylvatica* L.) with special regard to red heartwood formation. Gozdarski Vestnik 64: 355–376.

Keller, H. 1962: Von rotkern der buche. Schweizerische Zeitschrift fur Forstwesen 113: 498–502.

Knoke, T. 2002: Value of complete information on red heartwood formation in beech (*Fagus sylvatica* L.). Silva Fennica 36: 841–851.

Knoke, T. 2003: Felling strategies in beech stands (*Fagus sylvatica* L.) in the context of risks of red heartwood – a silvicultural/forest economics study. Forstliche Forschungsberichte Munchen 193: 11.

Knoke, T., S. S. Wenderoth 2001: An approach to predict probability and extent of red coloured heartwood in beech (*Fagus sylvatica* L.). Forstwissenschaftliches Centralblatt 120: 154–172.

Koch, G., J. Puls, J. Bauch 2003: Topochemical characterisation of phenolic extractives in discoloured beechwood (*Fagus sylvatica* L.). Holzforschung 57: 339–345.

Krempl, H., E. Mark 1962: Untersuchungen über den kern der rotbuche. Allgemeine Forst Zeitung 73: 186–191.

Kucera, L. 1991: Die buche und ihr holz eine einfuhrung in die problematik. Schweizerische Zeitschrift für Forstwesen 142: 363–373.

Kudra, V. S., R. M. Viter, Y. I. Gaida 2003: Effect of false heart on the quality of beech wood. Lesnoe Khozyaistvo 5: 23–24.

Mahler, G., B. Höwecke 1991: Verkernungserscheinungen bei der buche in Baden-Württenberg in abhängingkeit von alter, standort und durchmesser. Schweizerische Zeitzschrift für Forstwesen 142: 375–390.

Necesany, V. 1958: Jadro buku: struktura, vznik a vyvoj. Slovak Academy of Sciences, Bratislava, Slovakia.

Necesany, V. 1969: Forstliche aspekte bei der enstehung des falschkerns bei der buche. Holz Zentralblatt 95: 563–564.

Necesany, V. 1973a: Kinetics of secondary changes in living xylem. Pt. I. Time dependent formation of tyloses and polyphenolic substances. Holzforschung 27: 73–76.

Necesany, V. 1973b: Kinetics of secondary changes in living xylem. Pt. II. Some biophysical aspects. Holzforschung 27: 77–79.

Prka, M. 2003: Occurrence of false heartwood in beech trees and technical beech roundwood coming from thinning and preparatory felling in the area of Bjelovar Bilogora. Sumarski List 127: 467–474.

Racz, J., H. Schulz, W. Knigge 1961: Untersuchungen uber das auftreten des buchenrotkerns. Der Forst und Hölzwirt 16: 413–417.

Raunecker, H. 1956: Der buchenrotkern nur eine altersercheinung. Allgemeine Forst und Jagdzeitung 127: 16–31.

Sachsse, H. 1967: Uber das wasser/gas - verhaltnis im holzporenraum lebender bäume im hinblick auf die kernbildung. Holz als Roh und Werkstoff 25: 291–303.

Sachsse, H. 1991: Kerntypen der rotbuche. Forstarchiv 63: 238–242.

Shigo, A. L., E. H. Larson 1969: A Photo guide of the pattern discolouration and decay in living northern hardwoods trees. USDA RP-NE-127.

Schmidt, M., K. von Gadow, H. Hofle 2005: Occurrence and extent of facultative heart-wood formation in beech located on limestone and claystone sites in southern Lower Saxony. Allgemeine Forst Und Jagdzeitung 176: 200–212.

Schmidt, O., H. Mehringer 1989: Bacteria in beechwood from forest decline areas and their significance for wood discolouration. European Journal of Wood and Wood Products 47: 285–290.

Sorz, J., P. Hietz 2008: Is oxygen involved in beech (*Fagus sylvatica* L.) red heartwood formation? Trees – Structure and Function 22: 175–185.

STN EN 1316-1 2000: Hardwood round timber. Qualitative classification. Part 1: Oak and beech. Slovak office of standarts, metrology and testing, Bratislava, Slovakia.

Torelli, N. 1984: The ecology of discolored wood as illustrated by beech (*Fagus sylvatica* L.). IAWA Bulletin 5: 121–127.

Torelli, N. 2001: Response of trees to deep and superficial wounds as illustrated by beech (*Fagus sylvatica* L.) with particular emphasis on aetiology and ecology of wound initiated discoloured wood ("red heart"). A review. Gozdarski Vestnik 59: 85–94.

Vasilievič, J. 1974: Beech heartwood formation in the region of Zrinjska Gora Mountain (Croatia). Šumarski list 98: 475–520.

Walter, M., M., L. Kucera 1991: Vorkom und bedeutung verschiedener kernformen bei der buche (*Fagus silvatica* L.). Schweizerische Zeitschrift für Forstwesen 142: 391–406.

Wernsdörfer, H., T. Constant, F. Mothe, M. A. Badia, G. Nepveu, U. Seeling 2005: Detailed analysis of the geometric relationship between external traits and the shape of red heartwood in beech trees (*Fagus sylvatica* L.). Trees-Structure and Function 19: 482–491.

Ziegler, H. 1968: Biological aspects of heartwood formation. Holz als Roh und Werkstoff 26: 61–68.

Zycha, H. 1948: Über die kernbildung und verwandte vorgänge im holz der rotbuche. Forswissenschaftliches Zentrablatt 67: 80–109.

SAŽETAK: Neprava srž (crveno srce) i poremećaji u rastu debla bukovih stabala glavni su fenomeni koji značajno utječu na kvalitetu sirovog drva, a time značajno smanjuju financijsku vrijednost izrađenih sortimenata (Becker et al 2005). U posljednje vrijeme velik broj autora istražuje utjecaj uzgajivačkih metoda (njege i obnove sastojina) na kvalitetu drvnih sortimenata s gledišta pojavnosti neprave srži. (Knoke 2003, Kudra et al. 2003, Prka 2003, Schmidt et al. 2005, Kadunc 2006). Ranija istraživanja pokazala su da dob sastojine, promjer debla i sastojinski oblik (Mahler a Höwecke 1991) imaju značajan utjecaj na veličinu i učestalost pojavnosti neprave srži. Održavanje aktivnog parenhima u stanju visoke vlažnosti na presjeku bukovog debla ovisno je o volumenu krošnje stabla. Intenzivne visoke prorede utječu na manju

učestalost pojavnosti neprave srži, ako promatramo ciljani prsni promjer od 40 do 50 cm (Kudra et al. 2003, Kadunc 2006). Intenzivne visoke prorede utječu na ranije dostizanje ciljanog promjera debla.

Postoji mnogo čimbenika koji utječu na nastanak i dinamiku širenja neprave srži u bukovim sastojinama. Zbog toga je cilj ovoga rada procijeniti utjecaj različitih šumskouzgojnih zahvata koji utječu na razvoj krošanja stabala, te tako i na pojavnost i raširenost neprave srži uz homogenost sljedećih čimbenika (vrsta sastojine, tip tla, dob, nagib terena, nadmorska visina i sl.).

Kako bi se otklonio utjecaj navedenih čimbenika, odabrane su dvije sastojine koje se nalaze u neposrednoj blizini, dok su uzgojni zahvati u njima bili različiti. U sastojini na istraživačkoj plohi (CMT 513) 1980. godine postavljene su dvije trajne plohe (SPPs). Do 1980. godine bila je njegovana visokom proredom. Godine 1986. i 1991. u sastojini je izvršena selektivna proreda, a od 1991. do 2009. god. dva puta je izvršena preborna sječa u iznosu od 70–80 m^3 ha^{-1}. Druga sastojina 514 b ima četiri trajne plohe (SPPs) koje su osnovane 1966. godine visokom proredom usmjerenom na maksimalno oslobađanje prostora krošanja odabranih stabala. Intenzitet proreda za razdoblje od 5 godina do 1991. godine bio je na razini 16–18 %. U toj je godini izvršena posljednja proreda s intenzitetom 24–26 % drvne zalihe. Dendrometrijske značajke stabala mjerene su 1986, 1991,1997, 2001. i 2009. godine. Iz obje je sastojine odabrano po 14 stabala starosti u rasponu od 93 do 111 godina (tablice 1 i 2). Nakon rušenja i rezanja kolutova (sekcioniranja debla) na čelima je izmjerena širina neprave srži (RH) i piravosti (DZ).

Iz tablice 3 vidljivo je da se srednje vrijednosti volumena krošanja na istraživanim plohama značajno razlikuju s obzirom na različite metode prorede koje su provedene u protekle 23 godine. Iznimka je posljednje desetljeću 2001–2009. Srednja vrijednost volumena krošnje (razdoblje 1986–2001) za plohu CMT 513 23–35 % je veća nego na plohi CMT 514 b. Daljnje produkcijske značajke istraživanih sastojina vide se iz korelacijskih odnosa između visine stabla i prsnog promjera (slika 3) i između prsnog promjera i volumena krošnje (slika 4). S obzirom na veće srednje vrijednosti volumena krošanja tijekom razvoja, istraživačka ploha CMT 513 (tablica 3) imala je značajno niži stupanj pojavnosti neprave srži (RH) od pojavnosti na plohi 514b (slika 5). Isti faktor (tablica 3) nije značajno utjecao na udjel neprave srži (RH) (tablica 4). Iz tablice 4 također se može vidjeti da je razvoj krošnje utjecao na srednje vrijednosti udjela piravosti (DZ) (tablica 3). Niže vrijednosti veličine piravosti na istraživačkoj plohi CMT 513 prema plohi CMT 514 b (tablica 4) posljedica su prevencije oštećivanja debla, što je dovelo i do smanjenja pojavnosti neprave srži (RH).

Starenjem kambija širina piravosti i bijelji na stablima na obje se istraživačke plohe linearno povećavala (tablica 5). Suprotno tomu, rastom debla (H) oba su se faktora smanjivali (tablica 5). Statistički značajne korelacijske zavisnosti također ukazuju na jak utjecaj navedenih faktora. Analizom kvalitete izrađenih sortimenata (slika 7) potvrđena je viša kvaliteta sortimenata s istraživačke plohe CMT 513 u klasama A i B (STN EN1316-1). Suprotno tomu, udjel klase C bio je značajno niži nego li u sastojini 514 b.

Rezultati istraživanja potvrdili su da stablimično i dugotrajno uzgajanje bukve s krošnjom većom od polovice visine stabla u gornjoj etaži stvara preduvjete za postizanje željenog prsnog promjera od 45 do 50 cm (starost 100 do 110 godina) s vrlo malom pojavnosti neprave srži (RH). Stoga je uzgojne zahvate potrebno usmjeriti na formiranje kvalitetne donje trećine debla, koja prema Bachmanna (1990) predstavlja tek 60 % njegovog volumena, ali 90 % vrijednosti produkcije. Istraživana sastojina CMT 513 imala je značajno nižu učestalost pojavnosti neprave srži (RH) (slika 5). U usporedbi s literaturnim

podacima (Mahler and Höwecke 1991) učestalost pojavnosti neprave srži (RH) bila je značajno niža pri sličnim faktorima starosti od 100-120 godina i prsnom promjeru 40–49 cm. Prema Prki (2003), koji je istraživao problematiku obnove bukovih sastojina, učestalost pojavnosti neprave srži bila je oko 50 %. Dobiveni rezultati zbog toga nas upućuju na pretpostavku da se i u zreloj dobi stabala može pozitivno utjecati na odnos širine bijelji i piravosti (DZ). Primjerenim uzgajivačkim zahvatima koji su usmjereni na povećanje volumena i kvalitete krošnje smanjit će se pojavnost neprave srži (tablica 4 i slika 5). To će imati i značajan utjecaj na povećanje kvalitete i cijene izrađenih sortimenata (slika 7).

Ključne riječi: Fagus sylvatica *L., uzgajivački zahvati, neprava srž, bijelj, piravost*