CROWN STRUCTURE OF *PICEA OMORIKA* TREES IN THE PLANTATION

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Abstract - The study was carried out in Serbian spruce (*Picea omorika* Panč/Purkyně) plantations in the western Serbia. The paper presents results of the analysis of crown development. The following elements were analyzed: total tree height, height of the crown base, absolute and relative crown length, maximal crown diameter, coefficient of crown spreading and degree of crown girth. We discuss approaches to the modeling of tree crown growth and development, growing under favorable environmental and stand conditions, without anomalies in development. In order to establish the relationship between analyzed factors, regression analyses were applied. Data fitting was by the analytic method, by the implementation of Prodan's functions of growth, linear and parabolic function. Received models can be used for the simulation of various growth and developing processes in forest.

Key words: *Picea omorika*, plantation, crown form, regression models

INTRODUCTION

The Serbian spruce (*Picea omorika* Pančić/Purkyně) is the most famous endemo-relict species of the Balkan Peninsula. Primarily because of its rarity in European flora, but also because of the great opportunities for its practical use (Gilman and Watson, 1994) in plantations, this species has great significance. Contemporary problems in nature conservation in Serbia were presented by Stavretović (2010, 2011). The most detailed studies of Serbian spruce natural stands were reported by Čolić (1957), Stojanović (1995) and Ostojić (2005), while studies in plantations were done by Isajev (1987) and Bogdanović et al. (2005).

It is known that crown length and development is a complex indicator of the biological properties of the species and stand condition, based on which tree vitality is evaluated.

Crown structure and stem growth in the different forest species was researched and analyzed

by Sharma et al. (2002), Hummel (2009), Dubrasich et al. (1997), Fujimori (1993), Hemery et al. (2005), Krstic (2006), etc. According to Sharma et al. (2002), growing space was not a significant factor in the development of any of the evaluated response-variables: height, crown ratio, crown length, crown width and survival; however, it greatly affected the diameter at breast height (Dbh).

Crown ratio modeling has been reported by Soares and Tome (2001), Leites et al. (2009), Fengri et al. (1995), Hasenauer and Monserud (1996), Bechtold (2004), Krstić (2007), Govedar et al. (2003), Ostojić (2005) etc., and the reliability of tree crown position classification by Nicholas et al. (1991). Because the height/diameter ratio, the most important size variable, can also be considered an integrator of past competition, the crown ratio model is dominated by competition measures (Hasenauer and Monserud, 1996). Some morphometric characteristics in Serbian spruce plantations were researched by Kral (2002).

Despite the great number of studies, a detailed analysis of the quality, position of trees in stand, or other biological parameters of individual Serbian spruce trees has not been presented. Consequently, the aim of this paper is to study the structure and quality of Serbian spruce tree crowns and the crown form model in artificially established (*ex situ*) stands in field experiments.

MATERIALS AND METHODS

The measurements were made in Serbian spruce plantations, situated on the mountain massif Jelova Gora, in the western part of Serbia. The altitude is 990 m, exposure south, slope gradient 3-8°. The bedrock is schist; the soil is acid brown (dystric cambisol). Climate conditions of the region are characterized by a mean annual air temperature of 9.5°C, during the vegetation growth period 15.5°C, and average annual precipitation of 786 mm. According to Thornthwaite's climate analysis and classification, the climate is moderate humid (B_2 type).

The stand is artificially established on the montane beech site (*Asperula odoratae-Fagetum moesiacae* B. Jov. 1973). The stand is even-aged, 51 years old, with a complete canopy. The average total number of trees is 1336 per ha.

The standard working method was applied: the establishment of three sample plots and the collection of data during the forest operations. All the trees on the testing areas were measured for diameter and height – total and up to the first strong live branch: horizontal crown projection was recorded by the direct measure method. The trees were traditionally categorized into three biological height positions (classes): dominant (I b.pos.), codominant (II b.pos.) and suppressed (III b.pos.).

To determine the crown structure, the following elements were analyzed: total tree height (H_{tot}) height of the crown base (C_b), absolute and relative crown length (C_l), maximal crown diameter (C_w), coefficient of crown spreading (C_w/Dbh), and degree of crown girth (C_w/C_l). A comparative analysis of the crown structure of natural stands in natural sites (*in situ*) was conducted by Govedar et al. (2003) and Ostojić (2005).

The data were processed by regression analysis. Height curves were constructed based on the mean value per diameter degrees (Dbh). Data fitting was by the analytic method, by the implementation of Prodan's functions of growth. The method of modeling has been used, wherein the models have been expressed as regression equations that show in a simplified manner the relation of the analyzed elements. The statistical analysis performed in data processing were descriptive statistics, the Anderson-Darling goodness-of-fit test for tree distribution, and the T test for the determination of the difference between arithmetical means of data sets.

RESULTS AND DISCUSSION

Crown length depends on a variety of factors – tree species, shape of stands, canopy of stands, density, age, mixture, tree diameter, environmental conditions, etc.

The height of a crown's beginning in the studied stands increases abruptly, roughly to the diameter class of the mean stand diameter (21 cm), where it reaches its maximum and starts to decrease, which is a result of the different positions of the trees in the stand and a consequence of the struggle toward light. In thinner trees, which are found mainly in the suppressed story, the lower branches die more frequently due to the insufficient quantity of light, so that the height of the crown's beginning moves upwards more apparently. The thickest, and at the same time tallest, trees have the most developed crowns since they have provided themselves with enough life-space, and therefore the dying of the lower branches was either slowed down or completely stopped.

Tree differentiation in the stand

Of the total number of studied trees, the most numerous were trees of biological class I with 64%.

Table 1. Basic statistical data of the Serbian spruce (arithmetic means)

Element	Min	Max	Average	Stand. error	Coef. var. (%)
Dbh (mm)	135	273	203.1	2.76	12.5
Dbh I b.pos. (mm)	174	273	211.5	2.9	9.7
Dbh II b.pos. (mm)	159	222	183.3	2.9	18.2
Dbh III b.pos. (mm)	135	182	161.0	13.7	14.8
H_{tot} (m)	16.3	21.5	18.9	0.11	5.4
H I b.pos. (m)	17.3	21.5	19.2	0.12	4.6
H II b.pos. (m)	16.7	20.4	18.6	0.17	4.7
H III b.pos. (m)	16.3	16.7	16.5	0.13	1.4

Table 2. Parameters of regression models.

Model	R^2	F	S_e (m)
$H_{tot} = Dbh^2 / (7.77842 - 0.53563\ Dbh + 0.0598\ Dbh^2)$ (m)	0.989	310.7	0.13
$C_b = Dbh^2 / (16.96125 - 1.60302\ Dbh + 0.12265\ Dbh^2)$ (m)	0.611	7.1	0.29
$C_w = 0.37825 + 0.1189\ Dbh$ (m)	0.993	1019.3	0.048

One-third of the trees were of biological class II (32%), and the understory trees constituted only 4%. In the natural Serbian spruce stand, the upper layer includes 21% of the trees, one-third are in the middle layer, and 45% of the trees are in the lower layer (Govedar et al., 2003).

Basic statistical data are shown in Table 1. The average tree height is 18.9 m, of dominant stem 19.2 m, codominant stem 18.6 m, a and suppressed stem 16.5 m. That is approximately same height, which, according to Ostojić (2005), the Serbian spruce has on natural stands in natural sites. Identical diameter at breast height and height in Serbian spruce plantations in the Czech Republic was reported by Kral (2002).

By implementation of the T test for the determination of the difference between arithmetical means of data sets, it was concluded that the arithmetical means of the Dbh and tree height of Serbian spruce stems by biological class was statistically insignificant at p<0.05.

Absolute crown length

The studied stands showed a well-known tendency to increase in crown length with the increase in stem diameter (Fig. 1), which is in accordance with the natural process of trees growing faster in height in comparison with the speed of dying of the lower branches. This is also confirmed by the fact that the crowns of the medium among the dominant trees (20% of the thickest) were larger than the crowns of the mean stand trees.

Short crowns of trees in biological class III point to a significant deterioration in conditions for the development of suppressed trees.

Empirical data fitting was by the analytic method, the implementation of Prodan's and linear functions of growth. In this method regression equations of dependence of Serbian spruce tree height and tree diameter - $H_{tot} = f$ (Dbh), and dependence of crown base (Cb) height and tree diameter - $C_b = f$ (Dbh) (Table 2) are constructed.
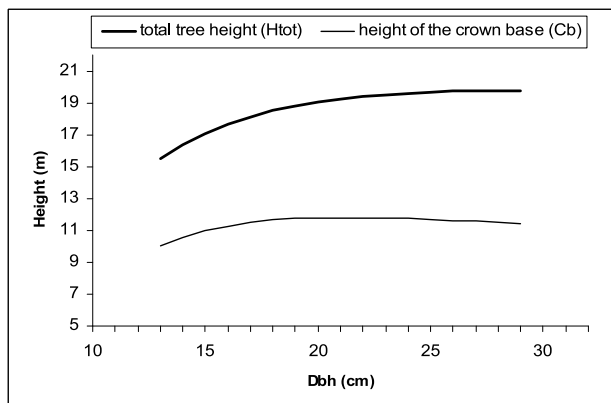
Fig. 1. Tree height and crown base height (m).

The dependence of H_{tot} is statistically significant at $p<0.01$, and it is explained for 99%. The dependence of C_b is statistically significant at $p<0.05$, and it is explained for 61%.

By using the tree height values (H_{tot}) and crown base height values (C_b), the values of crown length were obtained (Fig. 1, Table 3). It can be seen that the medium stand tree height was 19.14 m, the height of dominant medium tree was 19.35 m, and medium suppressed tree height was 17.74 m.

The height of the crown base (C_b) reflects the stand canopy structure and simultaneously indicates the demand for light of a tree species. The arithmetical mean of the heights of the crown bases in Serbian spruce, by biological classes, was statistically insignificant at $p<0.05$, which means that the position of a tree within artificially grown Serbian spruce monocultures does not have significant influence on the height of the crown base.

The height of the crown base was 11.31 to 11.79 m (Table 3). These are higher values than those in a natural stand (5.0-9.1m) reported by Ostojić (2005). This is consistent with the conclusion of Isajev et al. (2009) that in the selected population, the structure of the selected material will be less variable than that of the base material, i.e. the macro population with natural evolution.

Relative crown length (C_l/H_{tot})

Crown development was also obviously manifested by the relative crown length, which is the relationship between the length of the crown (C_l) and the height of the tree (H_{tot}). The relative crown length of medium stand trees was 0.38 (Table 3). This is almost identical to the data in the natural stands given for Serbian spruce (Ostojić, 2005), considered to be a very developed crown. According to Govedar et al. (2003), 66% of Serbian spruce trees have very elongated crowns – length above 1/3 of the total tree height. Approximately one third of all trees had crowns of medium length. Only 2% of trees had short crowns – less than ¼ of tree height.

The relative crown length of trees of certain categories also indicates the deterioration of conditions for the crown development of trees in the suppressed story, where the relative crown length was about 1/3 of the height of the tree.

Crown width (C_w)

In the studied stand, crown width was directly measured by the radius of four-sided axes from the main vertical stem axis (north, east, south, west), and from the terrain aspect as well.

The average crown radius of the medium tree was 1.4 m (1.35 do 1.42 m); of the dominant medium tree it is 1.51 m (1.45–1.56 m), medium intermediate tree 1.21 m (1.13-1.27 m), and medium suppressed tree 0.99 m (0.87-1.13 m).

By using the T test for the determination of the difference between arithmetical means of Serbian spruce crown radius, it was concluded to be statistically insignificant at $p<0.05$. I.e. the cardinal points or terrain exposition of man-made Serbian spruce stands does not have any significant influence on crown width.

The crown width of the Serbian spruce was calculated as a twofold value of the average width of the crown radius. These data were used for analysis of

Table 3. Basic statistical data of the Serbian spruce crown development according to model.

	H_{tot} (m)	C_b (m)	C_l (m)	R_{cl}	C_w (m)	C_w/Dbh	C_w/C_l
Dbh of stand	19.14	11.78	7.38	0.38	2.80	13.83	0.39
Dbh I b.pos.	19.35	11.79	7.59	0.39	2.95	13.73	0.40
Dbh II b.pos.	18.63	11.67	6.95	0.37	2.57	14.01	0.38
Dbh III b.pos.	17.74	11.31	6.73	0.36	2.30	14.21	0.36

the Dbh and crown width correlation. In this concrete case, it was best expressed by the linear form equation of regression. The dependence was statistically significant at p<0.01. The regression equation showed that with an increase in tree diameter of 1 cm, the crown increased by 12 cm.

The results imply that crown width ranges from 2.3 to 2.9 m, which is in line with the results obtained from natural stands (Ostojić, 2005). Therefore, crown width in Serbian spruce depends more on its inherent biological traits than on site conditions, canopy cover or tree origin, which is consonant with the conclusion drawn by Ostojić (2005) stating that Serbian spruce receives a sufficient amount of light for normal development even when the canopy closure is dense.

By using the T test it was concluded that the arithmetical means of crown width of Serbian spruce trees by biological class is statistically significant at p<0.05. This signifies that the biological position of a Serbian spruce tree in a stand has significant influence on tree crown width.

Coefficient of crown spreading (C_w/Dbh)

The development of diameter growth is greatly influenced by growth space, which can be regulated by thinning of appropriate intensity. The relationship between crown diameter and breast diameter of trees is the "coefficient of growth space" (C_w/Dbh).

In the studied stands, the coefficient of crown spreading – growth space varies between 13.2 and 14.5. In a medium stand tree it is 13.8 (Table 3) and

is somewhat lower than that in sessile oak, which is heliophyte, and is 15.2 to 29.1 (Krstić, 2006). Data analysis shows that the coefficient of crown spreading depends on site conditions – it is the lowest in stands in the most mesophilic conditions.

Data analysis shows that difference is more apparent in thin trees, which are mainly shorter, which complies with the supposition that the relationship of crown spreading is the smallest in trees in the first biological class, and largest in the third class.

Degree of crown girth (C_w/C_l)

This is also a characteristic indicator of crown development, which represents the relationship between the crown's width – crown's diameter (C_w) and its length (C_l). It depends on many factors, but is most prominently influenced by the biological characteristics of a species.

In the studied stands, the degree of crown girth in medium stand trees was 0.39, in dominant trees 0.40, and in suppressed trees 0.36. Such a relatively small difference in values of this coefficient is a consequence of species biological traits, i.e., Serbian spruce inherently has a very narrow crown (Table 3). According to Ostojić (2005), the coefficient varies from 0.33 to 0.68 for natural Serbian spruce stands, depending on site type, while for Sessile Oak as a heliophyte this value ranges from 0.45 to 0.88 (Krstić, 2006).

The structure of the tree crown has a high significance in silvicultural works because it is a very good indicator of silvicultural needs. A great increase in crown length in Serbian spruce trees with

an increase in diameter indicates the necessity to remove the thinner trees, which have less developed crowns, and consequently, much smaller growth. The short and stocky crowns of suppressed trees indicate a significant deterioration of conditions for the development of trees in the suppressed story, and these should therefore be removed by thinning.

Considering the modeling was applied at the stand level, received models can be used for computer-dynamic simulation of various growth and development processes of trees in a forest, and can be used for representation of crown growth by applying the two-dimensional tree crown model.

CONCLUSION

The height of the beginning of a live crown of the Serbian spruce abruptly increases, roughly to the diameter class in which the mean stand diameter is 21 cm, when it reaches its maximum and starts to decrease.

The absolute and relative crown lengths have a general tendency to increase with the increase in tree diameter. The length of the crown on the medium trees is between 1/3 and 1/2 of the height of the tree.

In the studied stands, the degree of crown girth in medium stand trees was 0.39, in dominant trees 0.40, and in suppressed trees 0.36. The coefficient of crown spreading decreases with the decrease in tree diameter, and reaches its highest value in trees of biological position III (suppressed).

In order to establish the relationship between the crown form elements of Serbian spruce trees, regression analyses have been applied; the results are as follows:

- the relationship between tree diameter and total Serbian spruce tree height, and tree diameter and crown base height is best expressed by Prodan's functions of growth: the dependence was statistically significant at p<0.01, i.e. p<0.05;

- crown diameter also shows great dependence of tree diameter; the dependence is significant at the level p<0.01.

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