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Biomass Production of Common Alder (*Alnus glutinosa* /L./ Gaertn.) in Pure Plantations and Mixed Plantations with Willow Clones (*Salix* sp.) in Croatia

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Abstract – Nacrtak

In the last two decades, Croatian energy policy was directed towards the increase of renewable energy sources in the total balance. It resulted in an increased interest for breeding fast-growing hardwoods in short rotations. Although common alder is not so productive in short rotations as some willows and poplars, insufficient development of the biomass market and increased awareness for conservation of domestic forest tree species, makes it favorable for raising plantations as it is the indigenous forest tree species that can be grown in longer rotations, if needed.

The estimate of above-ground dry biomass per tree (trunk and branches up to 7 cm in diameter) as well as production of biomass per hectare was made in 4 experimental plantations. The research included two mixed plantations of common alder open-pollinated families with willow clones (Salix sp.) and two pure common alder plantations. Experimental plantations, aged 14 and 16 years, are located in two different sites.

The estimated family mean values for dry biomass varied between 12.5 and 70.9 kg per tree. The results showed considerable differences between families as well as between different silvicultural treatments.

The estimated production of the common alder dry biomass varied between 27.4 and 87.5 t/ha with mean annual increments (MAI) between 1.9 and 6.3 t ha $^{-1}$ year $^{-1}$. It was shown that willow clones have a negative influence on the alder biomass in mixed plantations, at the studied plantation age. Willow clones have shown greater biomass production, compared with common alder, in spite the fact that its planting density was far lower. Although the planting density of common alder trees was lower compared to other studies, the average biomass production is within the framework of other results, which indicates significant potential of biomass production in local conditions.

The additive variance was not statistically significant for the biomass trait, which was probably caused by the dominant influence of microenvironmental factors (weed, game) during the growth, but also by a small number of studied families. Statistically significant interactions of investigated families with silvicultural treatments and sites have been shown, which directs to the genetically caused differences in the adaptability of families on studied site and growth differences.

Key words: open-pollinated families, genetic test, variation, genotype × environment interactions

1. Introduction – *Uvod*

The common alder (*Alnus glutinosa* /L./ Gaertn.) is spread all over Europe, from Ireland to the western Siberia, as far as the northern Africa and up to 60° in the northern Europe (Krstinić 1994). In Croatia, common alder grows in lowland forests along the rivers in pure or mixed stands with narrow-leaved ash (*Fraxinus angustifolia* Vahl.), European white elm (*Ulmus laevis* Pall.) and pedunculate oak

(*Quercus robur* L.). In some parts of northern Croatia along the river Drava, on humus-gley soil, common alder is the primary element of the association described as *Carici elongatae Alnetum glutinosae* W. Koch 1926. Localities of the phytocenosis belong to the most productive stands of common alder, with the tree heights above 30 m and volumes greater than 500 m^3/ha (Vukelić and Rauš 1998).

The Croatian energy policy is today directed towards increased efficiency, security of supply and diversification, market deregulation, and the use of renewals and environmental protection. The government launched a number of National Energy Programs in order to reach the goals of the energy policy, one of which (named BIOEN) is directly aimed at biomass and waste utilization (Domac et al. 1998, 2001). In regard to this, research work on the breeding of fast-growing hardwoods for the biomass production in short rotations has started.

Due to its biological characteristics common alder has a potential as a species for biomass production in short rotations. Earlier investigations in Croatia (Komlenović et al. 1996, Kajba et al. 1998, Bogdan 2002, Kajba et al. 2004, 2006), as well as in other countries (Saarsalmi 1995, Hytönen 1996) showed that common alder does not have such a high production capacity as some willow and poplar clones. However, considering the trend of conservation of natural forest species and undeveloped biomass market in Croatia, it is prospective for raising plantations as it is indigenous species and, depending on the market oscillations, can be grown in longer rotations.

Research on the production of alder biomass done so far include results from UK (Ovington 1956, Mitchell et al. 1981, Proe et al. 1999), Netherlands (Meeuwissen and Rottier 1984), Nordic and Baltic countries (Björklund and Ferm 1982, Rytter 1996, Saarsalmi and Mälkönen 1989, Saarsalmi et al. 1992, Korsmo 1995, Tullus et al. 1998, Uri and Tullus 1999, Uri et al. 2002) while the reports from South-Eastern Europe is scarce.

The aim of this investigation was to estimate the production of above ground dry biomass in present experimental plantations with open-pollinated families of common alder in Croatia, and to determine the variability of biomass trait within and between the investigated families in various growth and site conditions.

2. *Materials and methods – Materijal i metode*

2.1 Investigated plantations – *Istraživane kulture*

The research was done in four experimental plantations with open-pollinated families of common alder established at two sites in Croatia. Plants were grown from the seeds gathered in the existing clonal seed orchard.

The mixed plantation of common alder with willow clones (CJ1 plantation) is situated at the locality of Crni Jarci (46.0100 N; 17.1705 E). It is 16 years old and includes 18 open-pollinated families and 11 willow clones (Table 1). The trees of the common alder families were planted on a spacing of 4.0 × 2.0 m (1250 trees/ha) with ten trees per plot while willow clones were planted on a spacing of 4.0 × 4.0 m (625 trees/ha) between rows of alder. The trial was established according to the design of the randomized complete block system with four replications.

At the same time, right next to the above mentioned, a pure plantation of common alder (CJ2 plantation) was planted with a spacing of 2.5 × 2.0 m (2000 trees/ha) with 15 trees per plot according to the design of the randomized complete block system with four replications. There are 14 alder open-pollinated families in this plantation that are in common with CJ1 plantation.

The soil of the location of Crni Jarci belongs to the peat-gley type of hydromorphic soil (histic gleysol, according to the WRB soil classification), of somewhat acid reaction and well supplied with nutritions (Krstinić and Komlenović 1986).

At the locality of Lisicine (45.6615 N; 17.5072 E) a 14 year old mixed plantation was established (L1 plantation) with common alder open-pollinated families and single white willow clone 'V093'. Com-

Table 1 Investigated willow clones in mixed culture with common alder open-pollinated families – CJ1 (Clone 'V 093' is also planted in mixed plantation L1 – see Material and methods section)

Tablica 1. Istraživani klonovi vrbe uzgajani u mješovitoj kulturi s familijama crne johe – CJ1 (Klon 'V 093' je također posađen u mješovitoj kulturi L1 – v. Materijal i metode)

No. *Br.*	Clone label *Oznaka klona*	Botanical name *Botanički naziv*
1	'BR 1BB'	*Salix alba*
2	'MB 15'	*S. alba* × *S. a.* var. *vitellina*
3	'V 04'	*S. alba* var. *calva* × *S. alba*
4	'V 052'	*S. alba* var. *calva* × *S. alba*
5	'V 093'	(*S. alba* × *S. alba*. var. *vit.*) × *S. alba*
6	'V 158'	*Salix alba*
7	'V 160'	*Salix alba*
8	'V 161'	*Salix alba*
9	'V 217'	(*S. alba* × *S. sitchensis*) × *S. alba*
10	'V 218'	(*S. alba* × *S. sitchensis*) × *S. alba*
11	'V 219'	(*S. alba* × *S. sitchensis*) × *S. alba*

mon alder trees were planted with a spacing of 4.0 × 1.5 m (1667 trees/ha) with 18 trees per plot while the willow clone was planted with a spacing of 4.0 × 4.0 m between the rows of alder. There are 18 alder families in the plantation, but only 13 are in common with CJ1 plantation.

Nearby, a pure plantation of common alder was established (L2 plantation) according to the randomized complete block design. It consists of the same families and equal planting pattern as the plantation L1 and it is at the same age. It has nine open-pollinated families in common with the pure plantation CJ2.

The soil of this locality is characterized by pseudogley plateau (dystric planosol according to the WRB soil classification). The soil reaction is acidic, and the level of nutrition is lower than the level of adequate supplies for alder (Krstinić and Kajba 1991). In the vicinity of the researched plantations at the Lisicine site there is an artificial lake which secures higher air humidity during the growth period.

In all the mentioned plantations, no additional silvicultural (e. g. weed control, tending and fertilization) or protective measures have been implemented.

2.2 Growth measurements – *Izmjere rasta*

Diameter at breast height (DBH) and the height of each single tree were measured in all four plantations. Based on diameters and heights the volumes of trees were calculated using the Schumacher-Hall equations for the volume of common alder (Cestar and Kovačić 1982) and white willow (Cestar and Kovačić 1979). By the stated measurements the survival of studied families and clones was also determined.

2.3 Biomass estimate – *Procjena biomase*

The samples, based on which the biomass of the above-ground part of trees was estimated, were wood discs at breast height of the cut model trees. Model trees were determined by DBH variability of each single family and clone. In that way, four model trees were cut, respective of each studied family, clone and different trial. After taking the disks from the model trees, their fresh masses were measured. Minimum and maximum diameters of the discs were taken (d_{min}. and d_{max}.), together with the thickness in four points representing the beginning and end points of the minimum and maximum diameter (h_1, h_2, h_3, h_4). The volumes of the discs were determined using the formula for the volume of cylinder:

$$[V=(d/2^2)\pi h;$$
$$d=(d_{min}+d_{max})/2;$$
$$h=(h_1+h_2+h_3+h_4)/4]$$

Discs were dried at the temperature of 105°C until reaching the constant mass. Based on the volume of fresh discs and their dry mass, nominal densities were calculated:

$$\varphi_n = m_s \;/\; V_f$$

φ_n nominal density

m_s mass of dry ring

V_f volume of fresh ring

Based on mean values of nominal density for each family and clone (calculated as the mean of the nominal densities of the respective discs), and the calculated tree volumes (fresh volume), the dry biomass of each single tree were estimated. Since the calculated tree volumes regard the volume of trunks and branches up to 7 cm in diameter (Cestar and Kovačić 1979, 1982), the estimate of dry biomass also regards the dry biomass of trunks and branches up to 7 cm in diameter. This method is based on the somewhat modified method of determining the nominal tree density (ISO 3131, 1975).

The estimate of the dry biomass per hectare was done based on the mean values of each family and clone in each locality, with respect to actual planting spacing and survival percentage. The biomass was estimated and analyzed for 13 families that are common in both mixed plantations (CJ1 and L1) and 9 common families in both pure plantations (CJ2 and L2).

2.4 Statistical analysis – *Statističke analize*

The statistical analyses were done by the program package SAS System for Windows, ver. 6.12 (SAS Institute Inc. 1989).

The descriptive analysis was conducted for determining the mean values, variability range, standard deviations and coefficients of variability.

The analysis of variance was done using the GLM procedure in SAS (SAS Institute Inc. 1989). Expected mean squares, their coefficients and F tests were conducted for the purpose of testing the significance of the variances of single effects. Expected mean squares of error deviation were used as the denominator in the F tests.

The analysis of variance for the investigated common alder families was calculated separately for each single trial according to the following linear model:

$$Y_{ijk} = \mu + F_i + R_j + FR_{ij} + \varepsilon_{ijk} \quad (1)$$

Y_{ijk} observed measurement of tree *ijk*

μ a fixed overall mean

F_i effect of family *i* (*i* – 1,2,.....,*i*; depending on the test plot)

R_j effect of replication *j* (*j* – 1,2,.....*j*; depending on the test plot)

FR_{ij} effect of family i in replication j

ε_{ijk} random error

The analysis of variance was done for the common nine open-pollinated families, which were tested regarding two different treatments (mixed or pure plantations) with the aim of establishing the effect of the growth treatment according to the linear model:

$$Y_{ijkl} = \mu + T_i + R_{i(j)} + F_k + TF_{ik} + \varepsilon_{ijkl} \qquad (2)$$

Y_{ijkl} observed measurement of tree ijkl

μ a fixed overall mean

T_i effect of the treatment i (i – 1, 2)

F_k effect of family k (k – 1, 2,.....,9)

$R_{i(j)}$ effect of replication j in treatment i

TF_{ik} effect of family k in treatment i

ε_{ijkl} random error

The analysis of variance for the common open--pollinated families tested in two localities was done for the purpose of determining the effect of the site as well as the family × site interaction, according to the linear model:

$$Y_{ijkl} = \mu + L_i + R_{i(j)} + F_k + LF_{ik} + \varepsilon_{ijkl} \qquad (3)$$

Y_{ijkl} observed measurement of tree ijkl

μ a fixed overall mean

L_i effect of the locality i (i – 1, 2)

F_k effect of family k

$R_{i(j)}$ effect of replication j in a locality i

LF_{ik} effect of family k in locality i;

ε_{ijkl} random error

The analysis of variance for willow clones grown in association with the common alder open-pollinated families (plantation CJ1) was conducted using the following model:

$$Y_{ij} = \mu + C_i + \varepsilon_{ij} \qquad (4)$$

Y_{ij} observed measurement of tree ij

μ a overall mean

C_i effect of the clone i

ε_{ij} random error

All analyzed effects, except μ, were considered random and normally distributed.

2.5 Genetic parameters estimation – *Procjene genetskih parametara*

The REML method of VARCOMP procedure was used to estimate the variance components of all effects. Additive, genetic and phenotypic variances were estimated with the usual formulae (Wright 1976, Falconer and Mackay 1996):

$$\sigma_F = 1 / 4\, \sigma_a \qquad (5)$$

$$\sigma_{PH} = \sigma_F + \sigma_{FB} + \sigma_E \qquad (6)$$

$$\sigma_C = \sigma_G \qquad (7)$$

Where:

σ_F variance due to family effect

σ_A additive genetic variance

σ_G genetic variance

σ_C variance due to clone effect

σ_{PH} phenotypic variance

σ_{FB} variance due to family × block interaction

σ_F variance due to random error

3. Results – *Rezultati*

3.1 Above ground dry biomass – *Suha biomasa nadzemnoga dijela stabala*

A rather big variability can be noticed among the investigated common alder families in all trials (Tables 2, 3), but also a significant variability within the families, which can be seen from the high coeff. of variation. Generally, families 'B18' i 'B21' have shown the largest mean values, which is the indicator of the good general combining ability (GCA) of their mother trees.

Comparing the two plantations (CJ1 i CJ2), one can see the slightly higher mean values of the biomass of common alder families grown together with willow clones (Tables 2 and 3). Family 'B18' showed high biomass values in both trials, while the family 'B21' in the mixed plantation showed average value.

In the pure plantation Lisicine (L2) the common alder families had the highest mean dry biomass values in regard to all the other studied plantations (Table 3). Comparing the average values of the families in plantations L1 and L2, significant difference can be seen in the production, at the advantage of the pure plantation. The differences are so great that the family with the lowest mean value is better than the best family in the mixed plantation. Negative influence of willow on the total growth, as well as on the common alder biomass production is obvious.

Table 2 Descriptive statistical parameters for the above-ground dry biomass per tree (kg) of the common alder open-pollinated families grown in mixed plantations with willow clones

Tablica 2. *Deskriptivni statistički parametri familija crne johe uzgajanih u mješovitim kulturama s klonovima vrbe za svojstvo suha biomasa po stablu (kg)*

O. – P. *Familija*	Range *Opseg* ($x_{min.}$ – $x_{max.}$)	Mean *Arit. sredina* ($\bar{X}$)	Stand. Dev. *Stand. dev.* (s^2)	C.V. *Koficijent varijacije* (%)
Mixed culture – *Mješovita kultura* CJ1				
B1	1.44 – 65.20	23.84	19.43	81.51
B14	5.06 – 88.46	33.18	17.44	52.57
B15	5.72 – 80.65	37.79	20.50	54.24
B16	12.84 – 81.87	37.18	18.56	49.92
B17	1.29 – 91.83	26.63	23.55	88.43
B18	8.94 – 98.55	40.13	19.61	48.87
B21	4.30 – 80.29	31.47	23.49	74.67
B23	5.09 – 65.88	30.31	17.40	57.40
B29	7.92 – 88.08	34.75	21.28	61.24
B32	2.67 – 91.65	28.19	17.77	63.04
B4	6.22 – 74.16	25.68	15.67	61.01
B5	3.03 – 44.06	20.75	11.22	54.06
B7	4.23 – 133.75	32.38	29.94	92.47
Mean *Arit. sredina*		30.81	20.44	66.34
Mixed culture – *Mješovita kultura* L1				
B1	1.73 – 57.76	19.72	11.44	58.00
B14	0.05 – 3 8.82	16.84	10.40	61.76
B15	1.08 – 48.22	18.13	11.38	62.74
B16	0.96 – 82.65	20.00	17.07	85.35
B17	0.64 – 62.87	21.74	16.32	75.08
B18	3.04 – 72.39	33.12	20.97	63.31
B21	5.63 – 68.57	28.21	15.61	55.33
B23	2.85 – 41.00	17.93	10.79	60.20
B29	0.17 – 71.13	22.60	19.83	87.73
B32	2.74 – 61.58	23.56	14.79	62.79
B4	2.63 – 57.66	23.55	12.93	54.89
B5	0.97 – 29.65	12.55	7.94	63.28
B7	0.93 – 74.51	21.89	19.03	86.91
Mean Arit. sredina		21.71	15.48	71.28

Table 4 shows the results of the studied willow clones grown in the mixed plantation CJ1. It can be noticed that on average willow clones showed superior biomass production compared to common alder families. The clone 'V 219' had the lowest mean biomass, even lower than the majority of the alder families.

Table 3 Descriptive statistical parameters for the above-ground dry biomass per tree (kg) of the common alder open-pollinated families grown in pure plantations

Tablica 3. *Deskriptivni statistički parametri familija crne johe uzgajanih u čistim kulturama za svojstvo suha biomasa po stablu (kg)*

O. – P. *Familija*	Range *Opseg* ($x_{min.}$ – $x_{max.}$)	Mean *Arit. sredina* ($\bar{X}$)	Stand. Dev. *Stand. dev.* (s^2)	C.V. *Koficijent varijacije* (%)
Pure culture – *Čista kultura* CJ2				
B1	1.07 – 72.93	23.15	14.96	64.64
B14	1.24 – 67.04	24.71	13.97	56.54
B15	1.09 – 79.97	29.15	18.43	63.25
B17	0.99 – 180.78	34.29	28.52	83.18
B18	4.44 – 80.54	34.24	21.09	61.60
B21	4.27 – 103.66	37.57	23.42	62.35
B32	1.80 – 66.62	26.76	16.81	62.79
B5	0.72 – 71.37	28.71	17.32	60.34
B7	1.61 – 100.07	30.72	22.55	73.41
Mean *Arit. sredina*		29.59	20.39	68.91
Pure culture – *Čista kultura* L2				
B1	15.81 – 73.46	49.41	16.63	33.65
B14	8.07 – 126.69	63.00	26.85	42.63
B15	10.44 – 104.69	55.69	27.49	49.36
B17	16.45 – 90.01	55.05	22.18	40.28
B18	10.47 – 142.43	70.94	35.91	50.61
B21	21.28 – 111.35	63.96	27.71	43.32
B32	8.55 – 126.22	53.61	27.67	51.61
B5	3.35 – 87.14	37.77	18.77	49.69
B7	31.25 – 117.55	67.58	22.77	33.70
Mean *Arit. sredina*		57.65	27.64	47.94

3.2 Biomass production per hectare
Proizvodnja biomase po hektaru

The estimated above ground dry biomass production (trunks and branches up to 7cm in diameter) per hectare had the highest mean value in plantation L2 (87.5 t/ha), and lowest in CJ2 (27,4 t/ha) – see Figures 1 and 2. Mean annual increment (MAI) varied between 1.9 and 6.3 t ha^{-1} $year^{-1}$.

At the locality of Crni Jarci (Fig. 1) studied families showed slightly greater mean biomass production in the plantation where they were grown in association with willow clones, but also with wider planting spacings (4.0 × 2.0 m). Some families, in spite of that, have shown better production in treatment without willows ('B17', 'B21', 'B5', 'B7').

Table 4 Descriptive statistical parameters for the above-ground dry biomass per tree (kg) of the investigated willow clones grown in mixed plantations CJ1

Tablica 4. Deskriptivni statistički parametri klonova vrbe uzgajanih u mješovitoj kulturi s crnom johom CJ1, za svojstvo suhe biomase (kg)

O. – P. *Familija*	Range *Opseg* ($x_{min.}$ – $x_{max.}$)	Mean *Arit. sredina* ($\bar{X}$)	Stand. Dev. *Stand. dev* (s^2)	C.V. *Koficijent varijacije* (%)
'V 052'	11.61–376.38	123.43	109.72	88.89
'V 093'	10.50–315.71	95.35	62.89	65.95
'V 158'	16.92–202.78	83.41	54.01	64.75
'V 217'	15.49–183.12	78.57	48.40	61.60
'BR1BB'	10.47–175.41	65.69	48.95	74.51
'MB 15'	20.28–204.22	65.02	47.11	72.46
'V 160'	15.72–173.66	64.99	37.83	58.21
'V 218'	9.74–147.04	46.84	47.63	101.70
'V 04'	6.60–142.59	40.65	29.78	73.25
'V 161'	18.52–69.30	38.02	17.79	46.79
'V 219'	5.36–75.00	28.47	18.62	65.40
Mean *Arit. sredina*		78.25	63.78	81.51

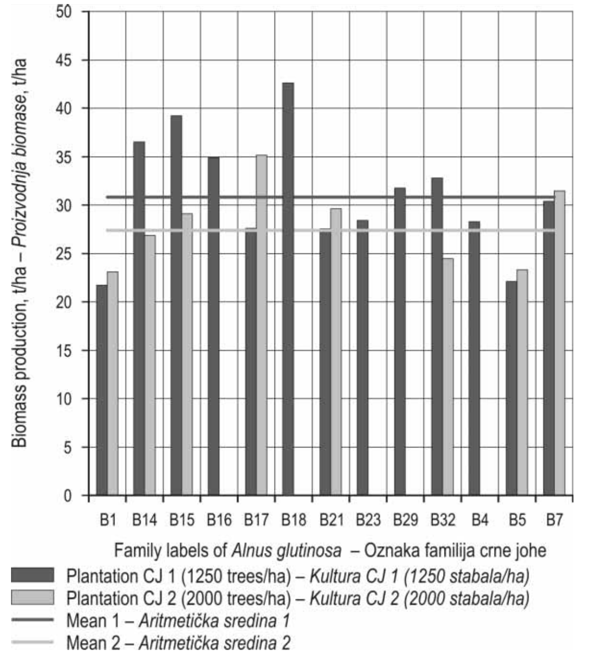

Fig. 1 Average above ground dry biomass production[1] of investigated common alder open-pollinated families grown in two different silvicultural treatments – locality of Crni Jarci

Slika 1. Prosječna proizvodnja suhe biomase nadzemnoga dijela istraživanih familija crne johe uzgajanih u dvjema plantažama na lokalitetu Crni jarci

Total average value of production of dry wood per hectare in the pure plantation L2 was 87.5 t/ha. Comparison of the average values of biomass production in the investigated common alder families in plantations L1 i L2 is presented in Fig 2. In opposite to the Crni Jarci locality, here, both treatments had the same planting spacings. Considerably better production of common alder biomass can be seen in pure plantation, where the families were grown without willows. The white willow clone 'V 093' had an 89% survival rate and the biomass production of 65.2 t/ha with considerably lower tree density (625 trees per hectare) in comparison with the common alder (2000 trees per ha).

Average biomass production of studied willow clones per hectare in the mixed plantation CJ1 was 32.8 t/ha (Fig. 3). However, clones 'V 052' and 'V 093' showed markedly higher biomass production that exceeded 50 t/ha.

Average survival of common alder open-pollinated families in mixed plantation L1 was somewhat better than in CJ1 (from 83% to 100%). The lowest production of biomass was by family 'B5' (19.3 t/ha), and the highest by 'B21' (47.0 t/ha) – Fig. 4. It can be seen that families showed different pattern of biomass production at two sites. For example, while family 'B 21' had the highest biomass production at L1 plantation it showed under average production at CJ1 plantation.

Fig. 5 presents the comparison between the average values of dry biomass production of common alder families grown without willow at two localities (CJ2 i L2). Higher productivity of all families at the locality of Lisicine, in spite of younger age, is rather surprising. However it could be explained by better site conditions at the Lisiscine site, but also by wider spacing between trees. Some families have shown considerably greater potential of biomass production (e. g. 'B7' – Fig. 5), their MAI being 7.6 tons ha^{-1} $year^{-1}$.

3.3 Genetic variation – *Genetska varijabilnost*

On the basis of the quantitative genetics theory, it is assumed that differences in quantitative traits between trees that belong to various open-pollinated families and grow within the same environmental conditions can be regarded to the genetic differences

[1] above ground biomass refer to estimated biomass of tree trunks and branches up to 7 cm in diameter

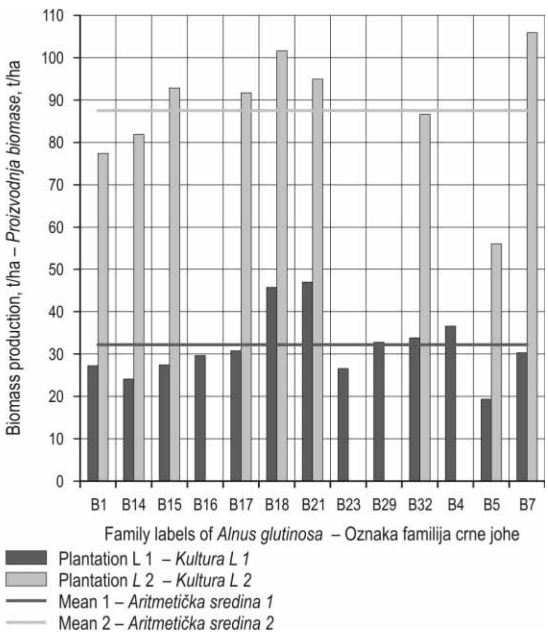

Fig. 2 Average above ground dry biomass production of investigated common alder open-pollinated families grown in two different silvicultural treatments – locality Lisicine

Slika 2. *Prosječna proizvodnja suhe biomase nadzemnoga dijela istraživanih familija crne johe uzgajanih u dvjema plantažama na lokalitetu Lisičine*

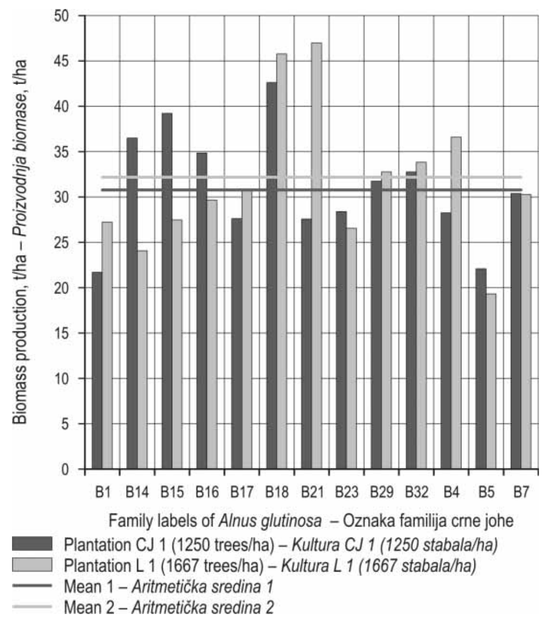

Fig. 4 Average above ground dry biomass production of common alder open-pollinated families. Comparison of the families grown in mixed plantations with willow clones in two different localities

Slika 4. *Prosječna proizvodnja suhe biomase nadzemnoga dijela familija crne johe. Usporedba familija uzgajanih u mješovitim kulturama s klonovima vrbe na dvama lokalitetima.*

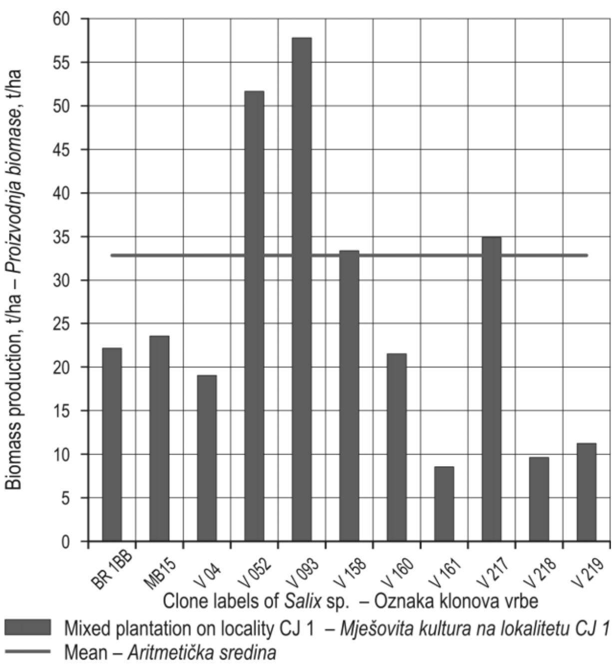

Fig. 3 Average above ground dry biomass production of investigated willow clones grown in mixed plantation with common alder – locality of Crni Jarci (CJ1; 625 trees per ha; 16 yrs old)

Slika 3. Prosječna proizvodnja biomase nadzemnoga dijela stabala istraživanih klonova vrbe uzgajanih u mješovitoj kulturi s crnom johom – lokalitet Crni jarci (CJ1; 625 stabala po ha; dob 16 godina)

between their mother trees (Falconer and Mackay 1996). As biomass of the tree is quantitative trait, variance components caused by family effect are considered as a major part of the genetically caused variance of the trait. Table 5 shows that variance components caused by the family effect were not statistically significant and took relatively small part of the total variance. The largest percentage of the family effect (but still not significant) was observed in data from the L2 plantation (Table 5). The major percentages of the total variation were observed for the error variance component but it can be seen that family by replication interactions also had significant effects.

3.4 Family by plantation establishment interaction – *Interakcija familija s načinom osnivanja plantaža*

The results of the combined analyses of variance for both plantations at the locality of Crni Jarci (combined CJ1 and CJ2) and Lisicine locality (combined L1 and L2) are shown in Table 6. The aim of those analyses was to determine a significance of the influence of the willow clones on the common alder biomass production as well as of the influence of different spacing of common alder trees on its biomass production (the so called »silvicultural treatment«

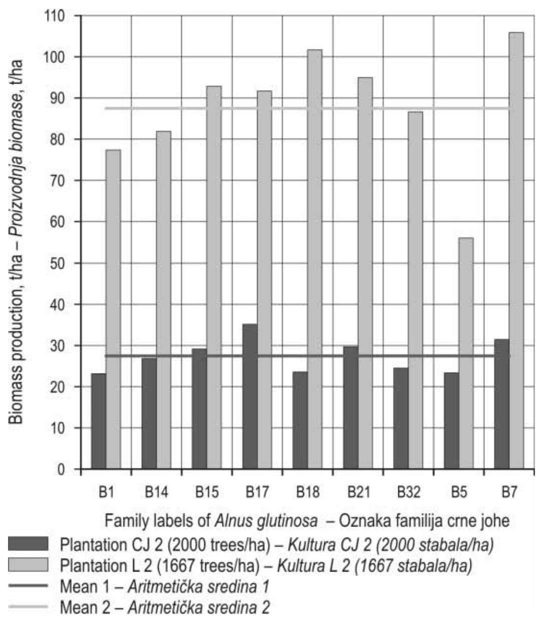

Fig. 5 Average above ground dry biomass production of common alder open-pollinated families. Comparison of the families grown in pure plantations in two different localities

Slika 5. *Prosječna proizvodnja suhe biomase nadzemnoga dijela familija crne johe. Usporedba familija uzgajanih u čistim kulturama na dvama lokalitetima.*

influence). It can be seen that treatment has caused significant variation at the locality of Lisicine, but not at the locality of Crni Jarci.

Also, it can be noticed that the effects of family by treatment interactions were statistically significant at both sites, which means that families had different responses to the studied silvicultural treatments.

3.5 Family × site interaction – *Interakcija familija sa stanišnim uvjetima*

The results of the combined analyses of variance for both sites but regarding the same silvicultural treatment (combined analyses of CJ1 and L1, as well as combined analyses of CJ2 and L2) are shown in Table 7. The aim of those analyses was to determine the significance of the influence of different site conditions on the common alder biomass production. The mean annual increment (MAI) was analyzed because of the different age of trees

The results showed statistically significant differences between the sites (for both types of plantations i.e. mixed and pure plantations), as well as statistically significant family by site interactions (with significance level of 0.05 and 0.01, respectively). The studied common alder families, grown in two pure plantations (CJ 2 and L2), have shown particularly high influence of environment (50% variance component caused by sites).

4. Discussion – *Rasprava*

4.1 Above ground dry biomass – *Suha biomasa nadzemnoga dijela stabala*

Taking into consideration a more uniform genetic structure of willow in comparison to common alder, great variation of biomass within clones is rather

Table 5 Variance components for the above-ground dry biomass trait of the common alder open-pollinated families in investigated plantations

Tablica 5. *Komponente varijance za svojstvo suhe biomase nadzemnog dijela stabala familija crne johe u istraživanim kulturama*

σ_f^2	%	σ_b^2	%	σ_{fxb}^2	(%)	σ_e^2	%	σ_A^2 (%)	σ_{PH}^2 (%)
Mixed culture – *Mješovita kultura* CJ1									
16.04^{ns}	3.8	0.00^{ns}	0.0	25.03^{*}	6.0	378.55	90.2	64.16 (15.3%)	419.62 (100%)
Pure culture – *Čista kultura* CJ1									
6.52^{ns}	1.6	0.00^{ns}	0.0	22.18^{*}	5.3	378.98	93.1	26.08 (6.4%)	407.68 (100%)
Mixed culture – *Mješovita kultura* L1									
1.113^{ns}	0.5	5.010^{ns}	2.1	32.723^{**}	13.5	203.624	84.0	4.45 (1.9%)	237.46 (100%)
Pure culture – *Čista kultura* L2									
55.464^{ns}	7.2	0.000^{ns}	0.0	73.785^{**}	9.5	644.562	83.3	221.86 (28.7%)	773.81 (100%)

σ_F^2 variance caused by family effect
σ_b^2 variance caused by replication
σ_{fxb}^2 variance caused by family × replication effect
σ_e^2 random error variance
σ_A^2 additive variance
σ_{PH}^2 phenotypic variance
* significance level $p < 0.05$
** significance level $p < 0.01$
ns not significant

Table 6 Variance components for the above – ground dry biomass of the studied common alder open – pollinated families. Family by plantation establishment interactions (mixed or pure cultures and different planting spacings – so called silvicultural treatment)

Tablica 6. *Komponente varijance za suhu biomasu nadzemnoga dijela stabala istraživanih familija crne johe. Interakcija familija s načinom osnivanja kulture (mješovita ili čista kultura te različiti razmak sadnje).*

σ_f^2	σ_b^2	σ_T^2	σ_{fxT}^2	σ_e^2	σ_A^2 (%)	σ_{PH}^2(%)
Locality – *Lokalitet* (*Crni jarci*)						
9.97^{ns} (2.3%)	1.45^{ns} (0.3%)	0.00^{ns} (0.0%)	8.95* (2.1%)	412.41 (95.3%)	39.88 (9.2%)	431.33 (100%)
Locality – *Lokalitet* (*Lisičine*)						
45.17* (4.1%)	0.00^{ns} (0.0%)	635.69** (58.4%)	12.70* (1.17%)	395.12 (36.3%)	180.68 (39.9%)	452.99 (100%)

σ_F^2 variance caused by family effect
σ_b^2 variance caused by replication
σ_T^2 variance caused by silvicultural treatments (mixed or pure culture)
σ_{fxT}^2 variance caused by family × treatment effect
σ_e^2 random error variance
σ_A^2 additive variance
σ_{PH}^2 phenotypic variance
* significance level p < 0.05
** significance level p < 0.01
ns not significant

surprising. It is most likely caused by the influence of microhabitat factors (e. g. weed, game) and the competition between alder and willow.

The estimated mean values of the above ground dry biomass are in accordance with dry weights of the total biomass production above stump level per tree presented by Johansson (2000) for common alder. Though alder biomass production is obviously much lower than willow, it is still significant. Moreover, if one takes into account larger market prices of alder wood, its ecological values (as well as public perception on indigenous forest species) and undeveloped biomass market in Croatia, it seems that alder plantations presently have greater potential than willows.

4.2 Biomass production per hectare *Proizvodnja biomase po hektaru*

Greater production of willow in regard to the common alder families, in spite of smaller number of trees per plot (planting spacing 4.0 × 4.0 m), is the consequence of their biological differences, i.e. more rapid growth of willows in the first years of life,

Table 7 Variance components for the above-ground dry biomass of the studied common alder open-pollinated families. Family by site interactions (the same silvicultural treatments at different sites)

Tablica 7. *Komponente varijance za suhu biomasu nadzemnoga dijela stabala istraživanih familija crne johe. Interakcija familija sa staništem (jednako osnovane kulture na različitom staništu).*

σ_f^2	σ_b^2	σ_L^2	σ_{fxL}^2	σ_e^2	σ_A^2 (%)	σ_{PH}^2 (%)
Mixed cultures – *Mješovite kulture*						
0.053^{ns} (3.6%)	0.015* (1.0%)	0.052*(3.6%)	0.037* (2.5%)	1.308 (89.2%)	0.212 (15.2%)	1.398 (100%)
Pure cultures – *Čiste kulture*						
0.084^{ns} (1.7%)	0.001^{ns} (0.0%)	2.497** (50.0%)	0.152** (3.1%)	2.257 (45.2%)	0.336 (13.5%)	2.493 (100%)

σ_F^2 variance caused by family effect
σ_b^2 variance caused by replication
σ_L^2 variance caused by sites (Crni Jarci and Lisicine)
σ_{fxL}^2 variance causd by family × site interaction
σ_e^2 random error variance
σ_A^2 additive variance
σ_{PH}^2 phenotypic variance
* significance level p < 0.05
** significance level p < 0.01
ns not significant

which was even more likely as the investigated clones are of superior growth even in regard to *Salix* species.

Different authors reported above ground biomass production for common and grey alder stands in Europe (Ovington 1956, Björklund and Ferm 1982, Rytter 1996, Saarsalmi and Mälkönen 1989, Saarsalmi et al. 1992, Korsmo 1995, Tullus et al. 1998, Uri et al. 2002) and USA (Wittwer and Stringer 1985). The reported mean annual increments varied between 1.8 (Meeuwissen and Rottier 1984) and 14.8 tons ha^{-1} $year^{-1}$ (Rytter 1996,Tullus et al. 1998). Mitchell et al. (1981) bring results on the above ground biomass production for 12 and 18 year old common alder stands (approximately the same age as plantations used in this study), which were 29.6 t/ha with 2.5 MAI and 87.2 t/ha with 4.8 MAI. The production of common alder biomass in plantations presented here is in the framework of other reports. However, the planting densities in our studied plantations were considerably lower. It shows that there is significant potential in increase of biomass production by planting plantations with greater plant density, under local conditions, especially by combining selection with favorable silvicultural treatments. Additionally, there is a great potential for effective harvesting method that could improve the economical basis for establishment of such plantations (Krpan and Poršinsky 2004).

4.3 Genetic variation – *Genetska varijabilnost*

Family effect as an indicator of genetic control was not a statistically significant factor, which shows that the environment (weed, game etc.) had a great impact on researched trait. Experimental error, which represents the variability within families and within replications, had the greatest share in the total variability (Table 5).

Small values of the additive variance could have also been influenced by lowered genetic variability because the trials include descendants of a small number of mother trees from the clonal seed orchard, in which the trees were selected by the superior growth traits, and are probably more genetically uniform. However, if one takes into consideration all studied plantations, it can be seen that greater differences in biomass production might be expected in more uniform environments (e.g. see Fig. 2 – production of the families at the plantation L2). Thus, the assumption that environmental impact caused small additive variance seems more reasonable.

4.4 Family by plantation establishment interaction – *Interakcija familija s načinom osnivanja plantaža*

Analyzed families are common in both types of tests (mixed and pure plantations), and the goal of the analyses was to determine the interaction of families and silvicultural treatments, i.e. growing common alder with or without the willow clones. For a more reliable testing of this interaction, other environmental factors should be eliminated. That was not done because of different spacing of alder trees (4.0 × 2.0 m and 2.5 × 2.0 m). For this reason the evaluation of the interaction is tampered with the influence of different spacings, and for the purpose of the exact evaluation of the influence of willow on the investigated alder families, the research should be repeated. Statistically significant interaction can be explained by differences in the influence of willow together with the influence of spacing on families, i.e. with specific adaptability of families to two different silvicultural treatments.

In the plantations L1 and L2, trees were planted in the same spacing, so the established interaction is a better indicator of willow's influence on the researched families. It was shown that the variance caused by treatments is statistically significant, with significance level of 0.01, which indicates the great influence of willow on all common alder families, which can be seen through decreased growth. However, a statistically significant family by treatment interaction was determined, with the significance level of 0.05, which indicates that the investigated families vary in their ability to compete with the willow.

Those results could be useful for selection of families, which showed better production in mixed plantations with willow clones. According to the earlier research done in Croatia (Kajba et al. 1999) it was shown that the mixed plantations have an increased height growth of common alder in regard to the pure plantations, but only until the age of 8 years, after which white willow overgrew and suppressed the alder. In compliance with these reports these authors recommended the establishment of mixed alder and willow plantations in order to increase the total biomass production and enhance biological stability, but with the need to cut the willow by the time of eight years old. Mixed plantations in this study were way over that age, which had a negative influence on the common alder biomass production.

4.5 Family × site interaction – *Interakcija familija sa stanišnim uvjetima*

Krstinić and Kajba (1991) investigated the mean annual increment for the height in the same plantations with the trees aged 4 and 6, and have also determined significant family by site interaction. The authors explained the interaction with the contrast of sites considering the soil type, level of nutritions and humidity, that is, for the different adaptability of the studied families to the mentioned differences.

Although the site on the locality of Crni Jarci is of higher quality (taking into consideration the soil type and nutrition) investigated families grew better in the locality of Lisicine, which Krstinić and Kajba (1991) explained by higher humidity during growth period (due to water accumulation nearby). With the given explanation and considering the age of trees, another possible reason for better growth of common alder families at Lisicine locality is wider tree spacing, which allowed better light interception.

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Sažetak

Proizvodnja biomase crne johe (Alnus glutinosa /L./ Gaertn.) u čistim kulturama i mješovitim kulturama s klonovima vrbe (Salix sp.) u Hrvatskoj

Energetska politika Hrvatske u posljednja je dva desetljeća usmjerena prema povećanju udjela korištenja obnovljivih izvora energije u ukupnoj energetskoj bilanci. Zbog toga je povećan interes za oplemenjivanje brzorastućih listača podizanjem tzv. energetskih kultura radi proizvodnje biomase u kratkim ophodnjama. Crna joha u tom smislu nije toliko produktivna kao neke vrste vrba ili topola, ali uzimajući u obzir nedovoljnu razvijenost tržišta biomasom u Hrvatskoj i u posljednje vrijeme pojačanu svijesti o važnosti očuvanja autohtonoga šumskoga drveća, ta se vrsta nameće pogodnom za podizanje energetskih kultura.

U radu su prikazani rezultati istraživanja proizvodnje biomase u četirima pokusnim kulturama crne johe osnovanim s familijama dobivenim slobodnim oprašivanjem plus stabala iz klonske sjemenske plantaže iz Šumarije Đurđevac. Dvije su pokusne kulture osnovane na lokalitetu Crni jarci (Šumarija Đurđevac), od kojih je prva (CJ1) mješovita kultura crne johe i različitih klonova vrbe, dok je druga čista kultura s familijama crne johe (CJ2). Druge su dvije kulture osnovane na lokalitetu Lisičine (Šumarija Voćin), od kojih je jedna mješovita kultura (L1) crne johe s jednim klonom bijele vrbe (oznake 'V 093'), a druga čista kultura crne johe (L2). Sve četiri pokusne kulture osnovane su sukladno dizajnu potpunoga blok-sustava sa slučajnim rasporedom u četiri ponavljanja (RCB dizajn). Prve su dvije kulture (CJ1 i CJ2) bile u dobi od 16 godina, dok su druge dvije (L1 i L2) bile u dobi od 14 godina. Razmak sadnje stabala crne johe u kulturi CJ1 bio je 4,0 × 2,0 m (1250 stabala po ha), u kulturi CJ2 2,5 × 2,0 m (2000 stabala po ha), a u kulturama L1 i L2 4,0 × 1,5 m (1667 stabala po ha). Vrba je u obje mješovite kulture (CJ1 i L1) posađena između redova crne johe u razmaku sadnje 4,0 × 4,0 m (627 stabala po ha).

Izmjere visine stabala i njihova promjera na prsnoj visini obavljene su na svim preživjelim stablima u svim četirima pokusnim kulturama, pri čemu je utvrđeno i preživljavanje familija crne johe odnosno klonova vrbe. Na temelju izmjerenih visina i prsnih promjera izračunati su volumeni stabala sukladno Schumacher-Hall-ovim jednadžbama prilagođenih koeficijenata za crnu johu i bijelu vrbu. Biomasa je procijenjena modificiranom metodom određivanja nominalne gustoće stabala, a na temelju prosušenih kolutova odrezanih s prsne visine modelnih stabala. Prema utvrđenoj varijabilnosti prsnih promjera izabrana su po četiri modelna stabla za svaku pojedinu familiju crne johe i za svaki klon vrbe. Nominalna gustoća kolutova izračunata je kao omjer njihove suhe mase i volumena u svježem stanju. Na temelju tako izračunatih nominalnih gustoća izračunata je suha biomasa

svakoga pojedinoga stabla kao umnožak procijenjene nominalne gustoće i volumena stabala. Budući da se volumeni stabala odnose na deblo i grane do 7 cm debljine, tako se i procijenjena biomasa odnosi na suhu biomasu debla i grana do 7 cm debljine. Proizvodnja suhe biomase po hektaru izračunata je na temelju srednjih vrijednosti biomase stabla, razmaka sadnje i preživljavanja, zasebno za svaku familiju crne johe odnosno klon vrbe.

Statističke analize obuhvatile su deskriptivnu analizu i analize varijance za svojstvo suhe biomase. Analize varijance provedene su s ciljevima ispitivanja signifikantnosti razlika među istraživanim familijama crne johe (značajnost varijance uzrokovane efektom familija) i među klonovima vrbe; utjecaja okoliša na svojstvo (ispitivanjem značajnosti varijanci uzrokovanih efektima blokova i varijance ostatka); ispitivanja značajnosti interakcije istraživanih familija crne johe s različitim tretmanima osnivanja kultura (misli se na tretmane s obzirom na čistu kulturu ili mješovitu kulturu crne johe s klonovima vrbe i na različite razmake sadnje crne johe); ispitivanja značajnosti interakcije istraživanih familija crne johe s različitim stanišnim uvjetima (lokalitetima pokusnih nasada). Statističke su analize omogućile izračunavanje tzv. kvantitativnih genetskih parametara pomoću kojih je kvantificirana genetski uvjetovana komponenta ukupne varijabilnosti svojstva suhe biomase.

Rezultati su pokazali izrazito visoku varijabilnost biomase među istraživanim familijama crne johe, ali i visoku varijabilnost unutar svake familije. Prosječna vrijednost suhe biomase stabla po pokusnim kulturama kretala se od 21,7 kg u kulturi L1 do 57,6 kg u kulturi L2. Gledano po familijama, prosječna vrijednost suhe biomase stabla kretala se između 20,7 i 40,1 kg u kulturi CJ1, između 12,5 i 33,1 kg u kulturi L1, 23,1 i 37,6 kg u kulturi CJ2 i na kraju između 37,8 i 70,9 kg u kulturi L2. Promatrajući izračunate koeficjente varijabilnosti može se uočiti visoka unutarfamilijarna varijabilnost toga svojstva (tablice 2 i 3). Istraživani klonovi vrbe pokazali su značajno veće vrijednosti suhe biomase stabla u odnosu na crnu johu (tablica 4). Procijenjena proizvodnja biomase po hektaru bila je najviša u kulturi L2 (87,5 t/ha), a najniža u kulturi CJ2 (27,4 t/ha). Proizvodnja po istraživanim familijama prikazana je na grafikonima 1 i 2. Proizvodnja suhe biomase istraživanih klonova vrbe u mješovitoj plantaži CJ1 kretala se od 6,0 do 55,5 t/ha (grafikon 3). U rezultatima je usporedno prikazana prosječna proizvodnja biomase istraživanih familija crne johe koje su rasle u mješovitim kulturama CJ1 i L1 i onih koje su bile zajedničke u čistim kulturama CJ2 i L2 (grafikoni 4 i 5).

Prema teorijskim postavkama kvantitativne genetike smatra se da su razlike u nekom kvantitativnom svojstvu među različitim familijama dobivenim slobodnim oprašivanjem, a koje rastu u istim okolišnim uvjetima, uvjetovane genetskim razlikama između majčinskih stabala. Budući da je biomasa tipično kvantitativno svojstvo, onda se varijance uzrokovane efektom familija smatraju genetski uvjetovanom komponentom varijabilnosti toga svojstva u istraživanim kulturama. Komponente varijance uzrokovane efektom familija nisu bile statistički značajne ni u jednoj istraživanoj kulturi (tablica 5). Najviše su vrijednosti imale varijance uzrokovane efektima interakcije familija s blokovima i ostatak.

Rezultati kombinirane analize varijance za iste familije crne johe koje su rasle u različitom tretmanu (čiste ili mješovite kulture) prikazani su u tablici 6. Može se uočiti da je tretman bio statistički značajan efekt na lokalitetu Lisičine. Interakcija istraživanih familija crne johe s tretmanom (načinom osnivanja kultura) bila je statistički značajan efekt na obama lokalitetima. Rezultati kombinirane analize varijance za familije koje su u istom tretmanu uzgajane na različitim staništima (dva lokaliteta) prikazani su u tablici 7. Staništa su bila statistički značajan izvor varijabilnosti, a utvrđena je i statistički značajna interakcija istraživanih familija i staništa.

Na temelju dobivenih rezultata raspravljena je proizvodnja biomase crne johe i vrbe na razini stabla i na jedinici površine. Uzimajući u obzir genetsku uniformnost vrbe u pokusnim kulturama, iznenađuje visoka varijabilnost suhe biomase stabala unutar klonova. Vjerojatni je uzrok takve pojave kombinirani utjecaj mikrostanišnih prilika, kao što su kompeticije s korovnom vegetacijom, šteta od glodavaca i divljači i kompeticije sa stablima crne johe.

Veća proizvodnja biomase klonova vrbe u usporedbi s crnom johom, usprkos manjemu broju stabala po jedinici površine, posljedica je njihovih bioloških razlika (brži rast u prvim godinama). Iako je crna joha pokazala značajno manji potencijal u odnosu na vrbu, utvrđena proizvodnja suhe biomase u okvirima je dosadašnjih istraživanja u Europi i SAD-u. Međutim, treba naglasiti da je gustoća stabala po jedinici površine u ovom istraživanju bila mnogo manja u odnosu na ostale radove. Ta činjenica govori o znatnoj mogućnosti povećanja proizvodnje biomase s većom gustoćom sadnje i dodatnom primjenom korisnih uzgojno-zaštitinih mjera.

Mali udio varijance uzrokovane efektom familija (kao pokazatelj genetske komponente varijabilnosti) vjerojatno je posljedica negativnoga utjecaja mikrostaništa (u obliku korovne vegetacije, glodavaca, divljači i kompeticije između stabala). Iako genetski uvjetovana varijanca nije bila statistički značajna, to ne znači da biomasa nije pod genetskom kontrolom, već to znači da je okoliš zamaskirao genetske razlike među istraživanim familijama crne johe. U prilog tomu ide i veći udio varijance uzrokovane efektom familija utvrđen u kulturi L2 u kojoj su okolišni uvjeti bili jednolikiji od ostalih kultura.

Utjecaj načina osnivanja kulture na istraživane familije crne johe (pri čemu se misli na sadnju u čistim ili mješovitim kulturama odnosno u različitim razmacima) potvrđeno je značajan. Ta činjenica upućuje na različitu sposobnost prilagodbe familija na testirane uvjete. Općenito je utvrđeno da klonovi vrbe negativno utječu na rast i biomasu crne johe, ali su neke familije pokazale veću proizvodnju upravo u mješovitoj kulturi. Ta je pojava zabilježena na lokalitetu Crni jarci na kojem je joha sađena u različitim razmacima pa se stoga bolja proizvodnja nekih familija u mješovitoj kulturi može pripisati i većemu razmaku među stablima. Utjecaj vrbe na proizvodnju biomase crne johe može se jasnije vidjeti promatrajući kulture na lokalitetu Lisičine jer je tamo joha posađena u jednakim razmacima u objema kulturama. Očit je negativan utjecaj klona vrbe na sve istraživane familije crne johe. Iako se ta informacija čini logičnom, treba napomenuti da je vrijednost mješovitih kultura u dodatnoj visokoj proizvodnji biomase vrbe koja može podići ekonomsku vrijednost, ali i biološku stabilnost takvih kultura (u smislu veće biološke raznolikosti). Međutim, već su prijašnja istraživanja pokazala da vrba agresivno nadvladava crnu johu nakon osme godine starosti kulture. Stoga bi radi veće ekonomičnosti i proizvodnosti iz mješovitih kultura trebalo odstranjivati vrbu do osme godine starosti.

Rezultati su pokazali značajne interakcije istraživanih familija crne johe s testiranim lokalitetima, što upućuje na različitu sposobnost prilagodbe familija na stanišne uvjete. Iako je stanište u Lisičinama bolje kakvoće, neke su familije pokazale veću proizvodnju biomase na lokalitetu Crni jarci. Taj podatak ukazuje na mogućnost selekcije familija koje su bolje prilagođene na staništa slabije kakvoće.

Ključne riječi: familije, genetički test, raznolikost, interakcija genotip × okoliš

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