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IMPACT OF ROOT GROWTH POTENTIAL ON EUROPEAN BLACK PINE (*Pinus nigra* Arnold) SEEDLING SURVIVAL

UTJECAJ POTENCIJALA RASTA KORIJENA NA PREŽIVLJAVANJE I RAST SADNICA CRNOG BORA (Pinus nigra Arnold)

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Abstract

This paper deals with the impact of root growth potential on the survival of the European Black Pine (Pinus nigra Arnold) seedlings in the period between 2004 and 2007. The root growth potential of the sampled two-year-old seedlings (2+0) was evaluated according to Burdett's scale after the seedlings transplanted in containers were left in a greenhouse for 28 days at optimum conditions for root development. The seedlings were laid out in the nursery in a randomized block and their survival was researched.

The seedlings whose root growth potential on Burdett's scale was 0,1 did not survive in the nursery part of the experiment while those whose potential measured 2,3,4 had a very high survival percentage. The comparison of seedlings classified according to Burdett's scale with the classes used in today's Croatian forestry reveals big differences and discrepancies. Many seedlings from lower classes or the discarded ones have a very high potential on Burdett's scale and would be much more suitable for field planting than the seedlings classified according to morphological parameters.

Key words: root growth potential (RGP), Burdett's scale, seedling survival, seedling quality, European Black Pine.

Saţetak

U radu je istraživan utjecaj potencijala rasta korijena na preživljavanje sadnica crnog bora u periodu od 2004-2007. godine. Uzorak ispitivanih sadnica bio je starosti 2 godine (2+0), njima je određen potencijal rasta korijena metodom presadnje sadnica u posude, stavljene 28 dana u staklenik na optimalne uvijete za razvoj korijena, nakon čega je prema Burdett-ovoj skali određena vrijednost potencijala rasta korijena. Sadnice su rasađene u rasadnik slučajnim blok rasporedom i utvrđivano je njihovo preživljavanje.

Sadnice sa potencijalom rasta korjena prema Burdettu 0 i 1 nisu preživjele u rasadničkom djelu testa, dok su sadnice s potencijalom 2,3,4 preživjele s vrlo velikim postotkom. Usporedbom sadnica razvrstanih prema Burdetovoj skali s klasama koje se koriste danas u šumarstvu Hrvatske, vidi se veliko ostupanje i nepodudaranje. Mnoge sadnice koje pripadaju nižim klasama ili otpadu imaju veliki potencijal prema Burdetu i bile bi puno bolje za sadnju na terenu nego sadnice klasirane prema morfološkim parametrima.

Ključne riječi: potencijal rasta korijena (PRK), Burdett-ova skala, preživljavanje sadnica, kvaliteta sadnica, crni bor.

INTRODUCTION
UVOD

Owing to its wide ecological valency the Black Pine is a species suitable for reforestation of difficult terrains (rocky grounds, quick sands, ravines etc.) (Ivančević, 1995). Although it easily adapts to all sites the seedlings of better quality guarantee a better reforestation success. The standard for seedling quality HRN D. Z2. 110 which has been in use in the nurseries in our country for a number of years classifies seedlings into quality classes with respect to their heights and/or root collar diameter.

However, these parameters for determining quality classes of forest seedlings do not tell us anything about the physiological condition of a plant which is crucial for its survival on the site.

Root growth potential-RGP, also known as root growth capacity, can be defined as the capacity of a seedling to initiate and develop new roots when growing in favourable conditions such as the temperature of 20°C, 16-hour photo period with minimum 25% of full sun light and optimum water and nutrient supply (Ritchie 1984). Initiation and development of several new roots over a short period of time ensures a better survival and growth of seedlings (Sutton 1980). There is a high correlation between root growth potential and the performance after transplanting. There are two ways of interpreting practical values of the root growth potential test. In this study we used the Burdett's scale for testing root growth potential (Burdett 1979). In most countries it has been accepted as a standard as it saves time and effort when measuring the growth of new roots.

Table 1 Burdett's scale for evaluating RGP (Burdett, 1979).
Tablica 1. Burdettova skala (Burdett, 1979) za procjenu PRK.

Root growth evaluation *Procjena rasta korijena*	Number of new roots *Broj novih korjenčića*
0	None *Ništa*
1	A few roots not longer than 1 cm *Poneki korjenčić, ne dulji od 1 cm*
2	1-3 roots longer than 1 cm *1-3 korjenčića duljih od 1 cm*
3	4-10 roots longer than 1 cm *4-10 korjenčića duljih od 1 cm*
4	11-30 roots longer than 1 cm *11-30 korjenčića duljih od 1 cm*
5	31-100 roots longer than 1 cm *31-100 korjenčića duljih od 1 cm*
6	101-300 roots longer than 1 cm *101-300 korjenčića duljih od 1 cm*
7	More than 300 roots longer than 1 cm *Više od 300 korjenčića duljih od 1 cm*

Root growth potential is just a possibility for roots to grow, which means it may or may not be fully expressed when a seedling is transplanted into an open field. According to the definition of the root growth potential, if a plant is transplanted into an environment with optimum conditions for root growth, it will fully express its root growth potential and vice versa. In winter and early spring the site factors are rarely favourable for root growth and the root growth potential will rarely reach ideal levels after a plant has been transplanted into a field. The timing for evaluation of seedling quality, including the root growth potential test, is very important. In terms of reforestation the best time for evaluating seedling quality, including the root growth potential, is as close to the transplantation as possible, as the seedling quality can change during storage and handling. Another ideal time for taking samples is just before a seedling is transported from the nursery.

According to Burdett (1987) root growth potential tests do not predict a real seedling survival which depends on the field conditions, but only the potential for its survival. In unfavourable field conditions the seedling potential may not be expressed. Root growth potential as an indicator of the capacity of a seedling to survive or grow has been used for many species such as Ponderosa Pine (*Pinus ponderosa* Dougl et Laws), (Stone and Jenkinson, 1971), Sitka Spruce (*Picea sitkensis* (Bong.) Carr), (Deans et al. 1990), Lodgepole Pine (*Pinus contorta* Dougl ex Loud), (Burdett et al 1983, Simpson 1990), Western Hemlock (*Tsuga heterophylla* (Raf.) Sarg.), (Simpson 1990), White Spruce (*Picea glauca* (Moench) Voss x *Picea engelmanni* Parry.) (Simpson 1990, Simpson et al. 1994) and Common Ash (*Fraxinus excelsior* L.) (O'Reilly et al. 2002).

Burdett (1987) claims that the root growth potential of a seedling also indicates its frost and stress resistance and sees a correlation with frost damages on the Black Spruce (*Picea mariana* (Mill.) Britton, Sterns at Poggenb) (Columbo and Glerum 1984). Our understanding of the relationship between the physiological status and the growth of new roots is a limiting factor for the application of the test. According to Folk and Grosnickle (1997) the problem can be solved by limiting field conditions during evaluation of the root growth potential and simulating real site conditions. When predicting reforestation success a better result is achieved if more methods for seedling quality evaluation are combined together. Jacobs (2009) gives a model of multiple morphological parameters as a much better method for evaluation of the capacity of a seedling to grow compared to single morphological parameters used for bare root seedlings of hardwood species in the central forest areas of the USA. In a research into the survival of Loblolly Pine (*Pinus taeda* L.) the criterion for determining stock quality with respect to their survival was the number of new roots whose length was 0,5 cm or more for evaluating root growth potential, and the seedling height/root length ratio calculated for 80% of the survived seedlings in the first year after the transplantation (Larsen et al. 1986). A successful integration of physiological and morphological parameters can enhance the evaluation of seedling quality.

MATERIAL AND METHODS
MATERIJALI I METODE

The forest management unit Zelendvor stretches between 16°11'1" and 16°13'20" of eastern longitude and between 46°9'48" and 46°21'51" of northern latitude.

The Black Pine seedlings were grown from the seed sown in 2002 and 2003. The seed was obtained from the Croatian Forest Research Institute, Jastrebarsko. According to the certificate it was collected in the Forest Administration Senj, Forestry Senj, Forest Unit Biljevine, section 7 from the natural seed stand not listed in the Register of Recognized Seed Stands (Article 60, NN 68/1998) in autumn 1997 by the workers from the Nursery Production Unit of the Croatian Forest Research Institute, Jastrebarsko. The seed was clean, its germination energy after 10 days was 73,5% and the seed germination 90,3%. There was 5% of empty seed. The moist content was 6,3%, the usage value 90,3% and the seed was sound. The seed was sown in germination beds in the nursery Zelendvor, Forestry Varaždin and on beds in the Nursery Močile, Forest Administration Koprivnica, Forestry Koprivnica. In the first year of the experiment (2004) two-year-old black pine seedlings were lifted from the nursery Zelendvor. At the beginning of March, 85 seedlings were randomly lifted from the germination beds as a larger quantity of seedlings was not available in the nursery. The following year a sample of 120 seedlings was taken from the nursery Močile. As the seedlings originated from the same seed lot (both nurseries have similar natural characteristics and the same production methods) they were treated as one group. We used a meter to measure seedling heights, a calliper to measure root collar diameter and a ruler do determine the total root length. After root pruning the seedlings were transplanted into round 22-litre containers filled with the media for growing conifers produced by Klasmann Gmbh. There were five seedlings in each container, and each container represented one repetition, i.e. there were a total of 41 repetitions. After the seedlings were watered to saturation, they were transported to the greenhouse of the Faculty of Forestry in Zagreb where they were kept for 28 days in the following conditions: 75-90 % of moist which was constantly checked with a hygrometer and air temperature from 22°C to 25°C. During the 13-hour photo period the seedlings were watered by misting every half an hour in order to supply them with a sufficient moist. Twenty-eight days later we manually counted the number of new roots and used a ruler to measure their length. After the root growth potential was evaluated on the Burdett's scale, the seedlings were placed back into the media filled containers where they were kept for a week to let them adjust to the temperature change after the greenhouse and in order to avoid the shock after transplanting into an open field.

The seedlings were planted into the soil which had been ploughed to about 25 cm depth the previous autumn and finely worked, manured and fertilized the following spring same as for the other seedlings in the nursery. In both nurseries the seedlings were laid out in random rectangular blocks. The spacing between the rows was 40 cm and between the seedlings 30 cm. In 2005 the procedure was repeated with 120 seedlings from the same seed lot taken from the nursery Močile, Forest Administration Koprivnica, Forestry Koprivnica. The seedlings were put in the greenhouse of the Agricultural and Veterinary School Arboretum Opeka, Vinica. They were watered by misting, the moist was kept between 75% and 90% and the day light temperature between 22°C and 25°C. Twenty-eight days later new roots were counted and measured. After evaluating the root growth potential on Burdett's scale the seedlings were put back into the media-filled containers where they stayed for a week to let them adjust to the temperature change outside the greenhouse in order to avoid the shock when transplanted into an open field. The seedlings were planted on the ground which had been ploughed to about 25 cm depth the previous autumn and finely worked, manured and fertilized the following spring same as for the other seedlings in the nursery. During the three-year period standard measures for preventive protection against fungal diseases, pests and weed were carried out on the fields with the test seedlings.

RESEARCH RESULTS
REZULTATI ISTRAŽIVANJA

Seedling survival
Preživljenje sadnica

The total of 205 two-year-old sampled seedlings (2+0) fell into 5 quality classes of root growth potential on Burdett's scale-class 0, class 1, class 2, class 3 and class 4. Only one seedling or 0,5% belonged to class 0, 10 seedlings or 5,0% belonged to class 1, 90 seedlings or 44,0% belonged to class 2, class 3 contained 82 or 39,8% of seedlings and in class 4 there were 21 or 10,7% of seedlings. The survived seedlings all belonged to classes 2, 3 and 4. The survival rate was not shown graphically over the years as the cases of dead seedlings were recorded only during the first year after transplanting while the number of seedlings remained stationary in the following years. The graph shows that seedling survival increases with a higher root growth potential and that the seedlings whose root growth potential on Burdett's scale was 0 or 1 did not survive.

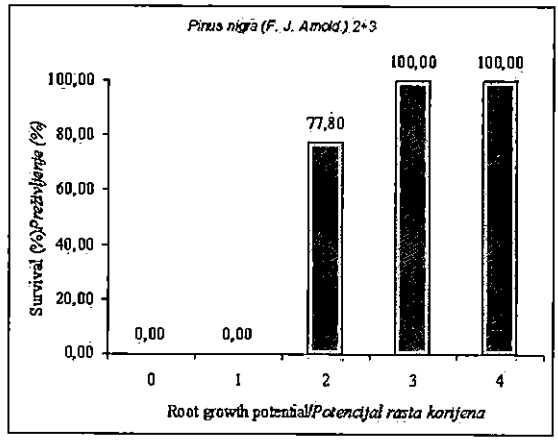

Figure 1 Survival of Black Pine seedlings (2+3) expressed in percentages based on the determined root growth potential (RGP).
Slika 1 Preživljenje sadnica crnog bora 2+3 u ovisnosti o potencijalu rasta korijena (PRK).

Table 2 Survival of Black Pine seedlings (2+3) expressed in percentages with respect to the determined root growth potential.
Tablica 2 Preživljenje sadnica crnog bora 2+3 u ovisnosti o potencijalu rasta korijena (PRK).

RGP *PRK*	Total of seedlings (pcs) *Ukupan broj sadnica (kom)*	Percentage of seedlings from samples (%) *Postotak sadnica iz uzorka (%)*	Survived (pcs) *Preživjelo (kom)*	Dead (pcs) *Propalo (kom)*	Survived (pcs) *Preživjelo (kom)*	Dead (pcs) *Propalo (kom)*
0	1	0,5	0	1	0	100
1	10	5	0	10	0	100
2	90	44	70	20	77,8	22,2
3	83	39,8	83	0	100	0
4	21	10,7	21	0	100	0
Total *Ukupno*	205	100	174	31	84,9	15,1

As seen from Table 2 most sampled seedlings fell into root growth potential classes 2, 3 and 4. 77,8% of the seedlings with root growth potential 2 survived while the seedlings with root growth potential 3 and 4 had a 100% survival rate. In the nurseries of Hrvatske Šume d.o.o., Zagreb, the largest producer of seedlings in Croatia, the classification of seedlings with respect to their height is performed on the basis of a reference table which includes age, production method, i.e. the time spent in germination beds or growing beds (table 3).

We will compare seedling heights based on age and the determined root growth potential with the classes corresponding to these heights if the seedlings were classified according to the methods used in the nurseries of Hrvatske Šume d.o.o., Zagreb.

Table 3 Reference table of height classes of the company Hrvatske Šume d.o.o.
Tablica 3 Visinske klase sadnica crnog bora koje se koriste u poduzeću „Hrvatske šume" d. o. o.

Age *Starost*	Visina (cm) *Seedling height (cm)*	Kvalitativna klasa *Quality class*
1+0	5-8	II. Klasa
1+0	8-12	I. Klasa
2+0	10-15	II. Klasa
2+0	15-20	I. Klasa
1+1	8-10	II. Klasa
1+1	10-15	I. Klasa
1+2	20-30	II. Klasa
1+2	30-40	I. Klasa
1+3	35-40	II. Klasa
1+3	40-50	I. Klasa
2+1	15-25	II. Klasa
2+1	25-30	I. Klasa
2+2	25-35	II. Klasa
2+2	35-50	I. Klasa

Table 4 shows numbers and percentages of the survived Black Pine seedlings of different ages and height classes as used in the nurseries of Hrvatske Šume d.o.o. with respect to the determined root growth potential.

Table 4 Height classes for Black Pine seedlings of different ages as used in the nurseries of Hrvatske Šume d.o.o. with respect to the determined root growth potential.
Tablica 4 Visinske klase sadnica crnog bora različite dobi used in the nurseries of Hrvatske Šume d.o.o. s obzirom na utvrđeni potencijal rasta korijena.

Age/RGP	2					3					4				
	>I	I	II	<II	Σ	>I	I	II	<II	Σ	>I	I	II	<II	Σ
2+0	2	21	39	8	70	4	25	41	13	83	3	14	4	0	21
%	2,86	30	55,71	11,43	100	4,82	30,12	49,4	15,66	100	14,29	66,67	19,05	0	100
2+1	3	15	49	3	70	5	16	55	7	83	2	10	9	0	21
%	4,29	21,43	70	4,29	100	6,02	19,28	66,27	8,43	100	9,52	47,62	42,86	0	100
2+2	-	-	-	-	-	1	22	52	8	83	2	8	11	0	21
%	-	-	-	-	-	1,2	26,51	62,65	9,64	100	9,52	38,1	52,38	0	100

The correlation between the heights of Black Pine seedlings 2+0 and root growth potential
Ovisnost visina sadnica crnog bora 2+0 i potencijala rasta korijena

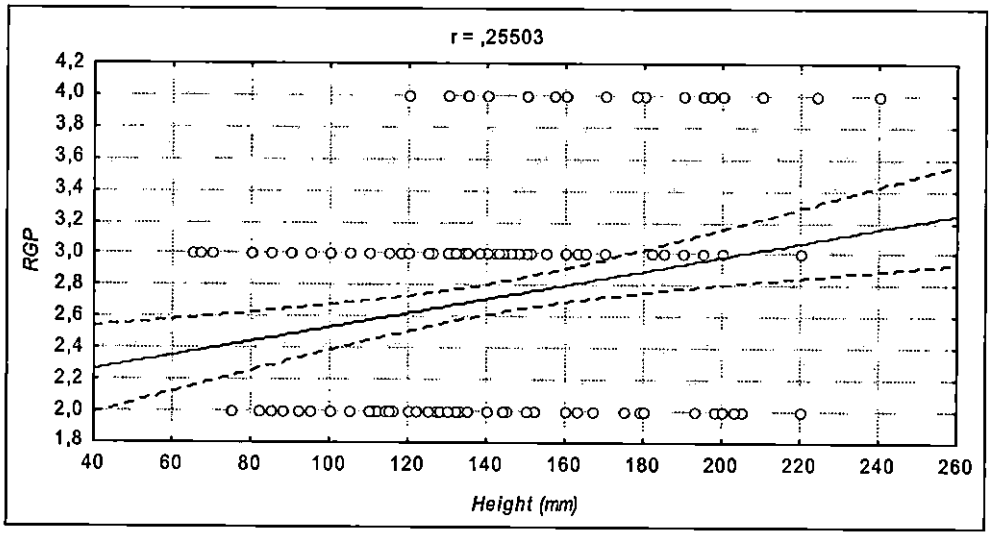

Figure 2 Correlation between the heights of Black Pine seedlings 2+0 and root growth potential
Figure 2 Korelacija između visina sadnica crnog bora 2+0 i potencijala rasta korijena

The correlation between seedling heights and root growth potential (r=0,25503) is positive.

Table 5 The variance analysis of Black Pine seedling heights 2+0 with respect to root growth potential.
Tablica 5 Analiza varijance visine sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

Source of variability *Izvor varijabilnosti*	SS	DF	MS	F	p
Constant *Konstanta*	2654816	1	2654816	2026,34	0,000000
RGP	28485	2	14243	10,871	0,000036
Deviations *Odstupanje*	222726	170	1310		

The variance analysis of Black Pine seedling heights 2+0 with respect to root growth potential showed a statistically significant difference (F=10,871, p=0,000036).

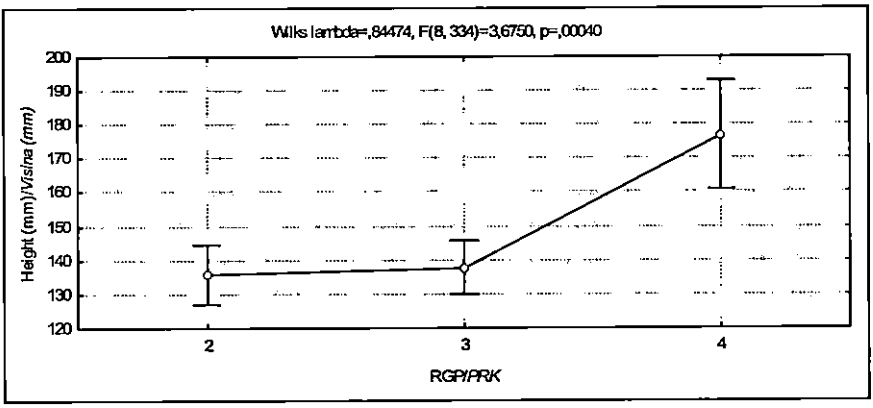

Figure 3 The variance analysis of Black Pine seedling heights 2+0 with respect to root growth potential.
Slika 3. Analiza varijance visina sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

Table 6 Tukey's *post hoc* test for Black Pine seedling heights 2+0 with respect to root growth potential.
Tablica 6. Tukeyev post hoc test visina sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

RGP *PRK*	2 (135,74)	3 (137,63)	4 (176,80)
2		0,944892	**0,000043**
3	0,944892		**0,000061**
4	**0,000043**	**0,000061**	

Tukey's *post hoc* test proved there was a statistically significant difference between seedling heights with root growth potential 4 and those with root growth potential 3 (p=0,000061) and 2 (p=0,000043). A statistically significant difference was also established for the seedlings aged 2+1 (F=4,791, p=0,009448). The heights of seedlings with root growth potential 4 were significantly different from those with root growth potential 3 (p=0,007933) and 2 (p=0,011739). A statistically significant difference was established for the seedlings aged 2+2 (F=6,606, p=0,001729). The heights of seedlings with root growth potential 4 were significantly different from those with root growth potential 3 (p=0,002387) and 2 (p=0,000832). A statistically significant difference (F=8,135, p=0,000422) was obtained for the seedlings aged 2+3.

There was a statistically significant difference between the heights of seedlings with root growth potential 4 and those with root growth potential 3 (p=0,002279) and 2 (p=0,000189).

Figure 3 clearly shows significant differences between the heights of seedlings with root growth potential 4 and those with root growth potential 2 and 3. The seedling heights with root growth potential 4 had an arithmetic mean of 176 mm and it ranged from 161 mm to 190 mm. The average value for the seedling heights with root growth potential 3 was 138 mm and it ranged from 129 mm to 146 mm. The seedling heights with root growth potential 2 had an average value of 136 mm, ranging from 128 mm to 144 mm.

The correlation between the shoot/root ratio of Black Pine seedlings2+0 and root growth potential

Ovisnost između odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 i potencijala rasta korijena

None of the seedlings with root growth potential 0 and 1 survived. The shoot/root ratio of the seedlings was round 1 or somewhat below. Table 7 shows the results of descriptive statistics for the shoot/root ratio of Black Pine seedlings 2+0 with respect to root growth potential.

Table 7 Descriptive statistics of the shoot/toot ratio of Black Pine seedlings 2+0 with respect to root growth potential.
Tablica 7. Deskriptivna statistika odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena

RGP	N	Mean *Aritm. sred.*	Std. dev. *Std. dev.*	Std. err. *Std. pogreška*	-95,00%	95,00%
2	71	0,686401	0,196886	0,023366	0,639799	0,733004
3	83	0,675145	0,180872	0,019853	0,63565	0,714639
4	20	0,81725	0,250482	0,05601	0,700021	0,934479
Total	174	0,696072	0,20007	0,015167	0,666135	0,726009

Table 7 clearly shows that the mean value of the shoot/root ratio of the seedlings with root growth potential 2 was 0,69. It does not statistically and significantly differ from the mean value of the shoot/root ratio of the seedlings with root growth potential 3 which was 0,68 but it differs from the seedlings with root growth potential 4 whose ratio was 0,82. The variance analysis of the shoot/root ratio of Black pine seedlings 2+0 with respect to root growth potential revealed a statistically significant difference (F=4,369, p=0,014104).

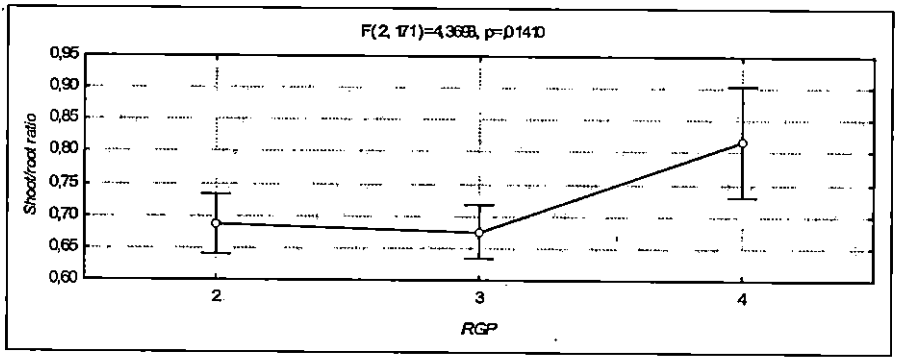

Figure 4 The variance analysis of the shoot/root length ratio of Black Pine seedlings 2+0 with respect to root growth potential.
Slika 4 Analiza varijance odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

Table 8 Tukey's post hoc test for the shoot/root length ratio of Black Pine seedlings 2+0 with respect to root growth potential. Tablica 8 Tukeyev post hoc test odnosa duljine nadzemnog i podzemnog dijela sadnica crnog bora 2+0 u odnosu na potencijal rasta korijena.

RGP *PRK*	2 (0,68640)	3 (0,67514)	4 (0,81725)
2		0,932983	**0,023014**
3	0,932983		**0,010227**
4	**0,023014**	**0,010227**	

Tukey's *post hoc* test established a statistically significant difference in shoot/root length ratio between the seedlings with root growth potential 4 and those with root growth potential 3 (p=0,010227) and 2 (p=0,023014).

DISCUSSION
RASPRAVA

The success of reforestation depends on the use of seedlings whose morphological and physiological characteristics ensure desirable heights, survival and a certain level of tolerance to unfavourable site conditions. It is the seedling quality that determines desirable height and survival after transplanting (Duryea 1985, Mattsson1997). The quality of a seedling is directly correlated to its genetic characteristics, size, vitality and especially the environment conditions at transplanting. It is directly influenced by the production method, the way of planting and storing. There are many studies on the quality of seedlings (Sutton1979, Ritchie 1984, Duryea 1985, Puttonen 1989, Grossnickle and Folk 1993, Mattsson 1979, Mohammed 1997, Puttonen 1997, Sampson et al. 1997, Tanaka et al. 1976). They mostly focused on the soil characteristics and physiological vitality of seedlings and less on the quality of the root system. However, there have been a few short studies directed towards morphological and physiological features of the root system with the purpose to determine methods for evaluating root system in seedlings.

A successful forest establishment largely depends on the ability of seedlings to form new roots fast (Grosnickle 2005). Formation of new roots can overcome transplantation shock and reduce a possible effect of slower seedling growth caused by poor adaptation to new site conditions (Rietveld 1989). Transplantation shock caused by water stress (Burdett 1990, Haase and Rose 1993) results in a reduced root growth and lesser contact between the soil and the root (Burdett 1990). The problem is more emphasized with bare root seedlings where the contact between the root and the soil is disturbed due to the loss of fine roots during lifting (Nambiar 1980, Struve and Joly 1992). The growth of new roots helps overcome the problem (Burdett et al. 1990, Nambiar and Sands 1993). The growth of new roots in conifers depends on photosynthesis (Van den Driessche 1987, Burdett 1990) and the level of water potential immediately after transplanting (Burdett 1990).

Among the total number of tested seedlings we determined the following 5 classes on Burdett's scale of root growth potential: class 0, class 1, class 2, class 3 and class 4. During the evaluation of RGP we did not use artificial light, which is partially why the seedlings did not exhibit a higher root growth potential than 4 on Burdett's scale.

The seedlings whose root growth potential on Burdett's scale was 0 and 1 did not survive the experiment. We can therefore conclude that the seedlings whose root growth potential is very low or inexistent, are not suitable for field planting as they are very unlikely to survive.

The seedlings with root growth potential 2 on Burdett's scale had a survival rate of 77,8%.

It can, therefore, be concluded that the seedlings with root growth potential 2 on Burdett's scale can be used for field planting. All the seedlings with root growth potential higher than 2 were among the survived ones, which means that the use of such seedlings ensures successful reforestation.

Morphological characteristics which can be easily measured (Ritchie 1984) are most frequently used in the process of seedling quality evaluation. The height and root collar diameter which are often used as parameters for determining nursery quality of seedlings are in many cases correlated to the survival of seedlings or to their height after transplanting (Thompson 1985, Bayley and Kietzka 1997,Jacobs 2009). However, long ago it was found out that seedling height and root collar diameter before reforestation cannot be correlated to seedling performance after transplanting (Chavase 1977, Thompson and Schultz 1995, Jacobs 2009). According to Wakeley (1949) there is very little interdependence between the height of southern pine seedlings and their survival after transplanting. Stone (1959) found out that the physiological condition of seedlings, especially expressed as the values of root growth potential at transplanting, can show a potential for the growth of root and stem if the seedlings have a certain level of tolerance to stress caused by reduced moist. When such research first started in the mid-twentieth century very few studies focused on the evaluation of the seedling root system as measuring root system is a hard and time consuming process dependent on soil characteristics.

The seedlings which according to the reference table of Hrvatske Šume d.o.o., Zagreb were mostly in height class 2 had the root growth potential 2 on Burdett's scale. The percentage of class 2 seedlings in our sample ranged from 55.71% for two-year-old seedlings to 70% for three-year-old seedlings and to 71.43% for four-year-old seedlings. The percentages of class 1 seedlings were much lower: 30% for two-year-old seedlings, 21.43% for three-year-old seedlings and 17.14% for four-year-old seedlings. The seedlings with height values below class 2 or above class 1 had the lowest percentages. There were 11.43% of two-year-old seedlings, 4.28% of three-year-old seedlings and 8.57% of four-year-old seedlings with height below class 2. There were 2.86% of two-year-old, 4.28% of three-year-old and 2.86% of four-year-old seedlings with heights above class 1.

The largest percentage of seedlings from height class 2 according to the reference table of Hrvatske Šume d.o.o., Zagreb had the root growth potential 3 on Burdett's scale. There were 49.40% of two-year-old, 66.26% of three-year-old and 62.65% of four-year-old seedlings. Among class 1 seedlings there were 30.12% of two-year-old, 19.28% of three-year-old and 26.51% of four-year-old seedlings. The seedlings with height values below class 2 or above class 1 had the lowest percentages. There were 15.66% of two-year-old, 8.44% of three-year-old and 9.64% of four-year-old seedlings with heights below class 2.

There were 4.82% of two-year-old, 6.02% of three-year-old and 1.20% of four-year-old seedlings with heights above class 1.

The largest percentage of seedlings with root growth potential 4 on Burdett's scale belonged to height classes 1 and 2 from the reference table of Hrvatske Šume d.o.o., Zagreb.

In class 1 there were 66.67% of two-year-old, 47.62% of three-year-old and 38.10% of four year-old seedlings. In class 2 there were 19.05% of two-year-old, 42.86% of three-year-old and 52.38% of four-year-old seedlings. The seedlings above class 1 values had the lowest share. It can also be observed that the group of survived seedlings with root growth potential 4 on Burdett's scale does not contain the seedlings with height values below class 2, unlike root growth potential 2 and 3 on Burdett's scale.

Among the seedlings with values above class 1 there were 14.28% of two-year-old, 9.52% of three-year-old and 9.52% of four-year-old seedlings.

Out of the total number of the survived seedlings 44% had the determined root growth potential 2 according to Burdett, 39.8% had the determined root growth potential 3 according to Burdett and for only 10.7% the determined root growth potential was 4 on Burdett's scale.

We noticed that the group with root growth potential 2 on Burdett's scale contained a large percentage of class 2 seedlings according to the classification system of Hrvatske Šume d.o.o., Zagreb. It is therefore evident that the stock group with root growth potential 2 on Burdett's scale is most similar to height class 2.

We also observed that the percentage of class 2 seedlings is lower for the group with root growth potential 3 on Burdett's scale, while the group with root growth potential 4 on Burdett's scale has a significant number of class 1 seedlings and there are no seedlings with heights below class 2 values. The stock group with root growth potential 4 on Burdett's scale is of different quality compared to the group with root growth potential 2 and 3 with respect to seedling heights. The result is also a hundred percent survival rate at the age of five.

The research established a statistically significant correlation between the height of seedlings and root growth potential. The variance analysis revealed a statistically significant difference in heights of Black pine seedlings 2+0 with root growth potential 4 compared to the heights of seedlings with root growth potential 2 and 3. There are statistically significant differences in seedling heights with higher root growth potential values.

A favourable shoot/root ratio has an important impact on the survival of seedlings after planting (Lopushinsky and Beebe 1976). A statistically significant difference in shoot/root ratio was established with respect to root growth potential. The shoot/root ratio of seedlings with root growth potential 4 was statistically different from the values for the seedlings with the determined root growth potential 2 and 3.

CONCLUSIONS
ZAKLJUČCI

The seedlings with root growth potential 2 (according to Burdett) had a survival rate of 77,8%. The seedlings with root growth potential 3 and 4 had a survival rate of 100%. The seedlings whose root growth potential was 0 and 1 (on Burdett's scale) did not survive.

There is a positive and strong correlation between root growth potential and seedling survival.

Root growth potential is a better indicator of nursery quality of seedlings compared to the height classes currently used in the nurseries in Croatia as they give a better insight into a potential for seedling survival at reforestation.

Seedling with higher root growth potential have better *shoot/root ratio.*

Performing root growth potential test usually requires a longer period of time. Therefore, this method can be suitable only for larger seedling lots while some other methods based on morphological parameters will continue to be used.

In order to get a better insight into the impact of root growth potential on seedling survival, further research should be done with field transplantation of seedlings in more severe conditions.

REFERENCES
LITERATURA

Bayley, A. D., J. W. Kietzka, 1997: Stock quality and field performsnce of *Pinus patula* seedlings produced under two nursery growing regimes during 7 different nursery production periods. New Forest, 13: 341-356.

Burdett, A. N., 1979: New methods for measuring root growth capacity their value in assessing lodgepole pine stock quality. Can. J. Forest Res., 9: 63-67.

Burdett, A. N., D. G. Simpson, C. F. Thompson, 1983: Root development and plantation establishment success. Plant and Soil, 71:103-110.

Burdett, A. N., 1987: Understanding root growth capacity: teoreticaly consideration in assesing planting stock quality by means of root growth test. Can. J. F. Res., 17: 768-775.

Burdett, A. N., 1990: Physiological processes in plantation stablishment and development of specifications for forest planting stock. Can. J. F. Res., 20: 415-427.

Chavasse, C. G. R., 1977: The significance of planting height as an indicator of subsequent seedlings growth. New Zealand J. For., 22: 283-296.

Colombo, S. J., C. Glerum, 1984: Winter injury to shoot as it affect root activity in black spruce container seedlings. Ca. J. F. Res., 14: 31-32.

Deans, J. D., C. Lundberg, M. G. R. Cannell, M. B. Murray, L. J. Sheppard, 1990: Root system fibrosity of Sitka spruce transplants: relationship with root growth potential. Forestry, 63: 1–7.

Duryea, M. L., 1985: "Evaluating seedlings quality importance to reforestration", u: Duryea, M. L. (ed.), Evaluating seedlings quality: Principles, Procedures and Predictiv Abilities o Major Tests, Forest Research Laboratory, Oregon State Universty, Corvallis, str. 1-6.

Folk, R. S., S. C. Grossnickle, 1997: Determining field performance potential with the use of limiting environmental conditions. New For., 13: 121-138.

Grossnickle, S. C., R. S. Folk, 1993: Stock quality assessment forecasting survival or performance on a reforestration site. Tree Planters Notes, 44: 113-121.

Grossnickle, S. C., 2005: The importance of root growth in overcoming planting stres. New Forests, 30: 273-294.

Hase, D. L., R. Rose, 1993: Soil moisture stres induces transplant shock in stored and unstored 2+0 Douglas-fir seedlings of vary root volume. For. Sci., 39: 275-294.

HRN D. Z2.110, http://www.hzn.hr/pdf/Oglasnik109.pdf

Ivančević, V., 1995: Šume i šumarstvo dijela hrvatskog primorskog krša tijekom XIX i XX vijeka (disertacija), Šumarski fakultet, Zagreb.

Jacobs, D. F., 2009: Drought susceptibility and recovery of transplanted *Quercus rubra* seedlings in relation to root system morphology. Annals of Forest Science, 66.

Lafayete IN, USA 19-20 October 2004, USDA For. Ser. Nord Central Research Station.

Larsen, H. S., D. B. South, J. M. Boyer, 1986: Root growth potential, seedling morfology and bud dormancy correlae with survival of loblolly pine seedlings planted in December in Alabama, Heron Publishing Victoria, Canada. Tree Physiology, 1: 253-263.

Lopushinsky, W., T. Beebe 1976: Relationship of shoot-root ratio to survival and growth of outplanted Douglas-fir and ponderosa pine seedlings. U.S.D.A. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note PNW-274 7 p.

Mattsson, A., 1997: Predicting field performance using seedlings quality assessment. New Forest, 13: 227-252.

Mohammed, G. H., 1997: The status and future of stock quality testing. New Forest, 13: 491-514.

Nambiar, E. K. S., R. Sands, 1993: Competition for water and nutrients in forest. Can. J. For. Res., 23: 1955-1968.

O'Reilly, C., C. Harper, M. Keane, 2002: Influence on physiological condition at the time of lifting on the cold storage tolerance of the field performance of ash and sycamore. Forestry, 75: 1-12.

Puttonen, P., 1989: Criteria for using seedlings performance potential tests. New Forest, 3: 67-87.

Rietveld, W. J., 1989: Transplanting stres in bareroot coniffer seedlings, its development and progresion to establishment. North J. Appl. For., 6: 99-107.

Ritchie, G. A., 1984: "Assessing seedling quality", u: Forest nursery manual: production of bareroot seedlings, Edited by M. L. Duryea and T. D. Landis Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, str. 243-266.

Sampson, P. H., C. W. G. Templeton, S. J. Colombo, 1997: An overview of Ontario stock quality assessments program. New For., 13: 469-487.

Simpson, D. G., 1990: Frost hardiness, root growth capacity and field performans relationship in interior spruce, lodgepole pine, Douglas-fir and western hemlock seedlings. Can. J. For. Res., 20: 566-572.

Simpson, D. G., C. F. Thompson, C. D. Southerland, 1994: Field performance of interior spruce seedlings effects of stres tretments and prediction by root growth potential and needle conductance. Can. J. For. Res., 24: 576-586.

Stone, E. C., G. H. Schubert, 1959: Root regeneration by ponderosa pine seedlings lifted at diferent times of the year. For. Sci., 5: 322-332.

Stone, E. C., J. L. Jenkinson, 1971: Physiologycal grading of ponderosa pine nursery stock. J. For., 69: 31-33.

Struve, D. K., R. J. Joly, 1992: Transplanted red oak seedlings mediate transplant shock by reducing leaf area and altering carbon allocation. Can. J. For. Res., 22: 1441–1448.

Sutton, R. F., 1979: Planting stock quality and grading. For. Ecol. Manage, 2: 123-132.

Sutton, R. F., 1980: Root system morphogenesi. N. Z. J. For. Sci., 10: 264-292.

Tanaka, Y., J. D. Walstad, J. E. Borrecco, 1976: The efect of wrenching on morphology and field performance of Douglas-fir and loblolly pine seedlings. Can. J. For. Res., 6: 453-458.

Thompson, B. E., 1985: "Seedlings morphologycal evaluation: what you can tell by looking", u: Duryea, M. I., Evaluating seedlings quality: Principels, Procedures and Predictive Ability of Mayor Tests, Oregon State University, Corvallis, OR, str. 59-71.

Von den Driessche, R., 1987: Importance of current photosynthate to new root growth in planted conifera seedlings. Can. J. For. Res. 17: 776-782.

Wakeley, P. C., 1949: "Physiologic grades of southern pine nursery stock", u: Shirley, H. I. (ed.), Proceeding of the 1948 Society of American Forest Annual Convention, Boston, MA USA.