DOI: 10.2478/frp-2013-0012

Leśne Prace Badawcze (*Forest Research Papers*), June 2013, Vol. 74 (2): 117–125.

ORIGINAL RESEARCH ARTICLE

Substrate influences the height of one- and two-year-old seedlings of silver fir and European beech growing in polystyrene containers

Jacek Banach✉, Kinga Skrzyszewska, Łukasz Świeboda

University of Agriculture in Krakow, Faculty of Forestry, Department of Genetics and Forest Tree Breeding, Al. 29 Listopada 46, 31-425 Kraków, Poland,

✉ Tel: + 48 12 66251259, Fax +48 126625128, e-mail: rlbanach@cyf-kr.edu.pl

Abstract. The effectiveness of different peat-based substrates was compared for the propagation of two mountain tree species (silver fir and European beech). The experiment was set up in the spring of 2006, and seedlings were grown in polystyrene multipots for 2 years. Four types of substrate were applied: (1) a newly prepared 1:1 peat-sawdust mixture; (2) a peat-sawdust mixture which had already been used for five production periods; (3) a peat substrate produced in the 'Nędza' container nursery (Rudy Raciborskie Forest District), consisting of peat and perlite; (4) a peat substrate, as described for (3), with added mycorrhizal fungus *Hebeloma crustuliniforme*. After sowing, polystyrene multi-pots were placed in a transparent tent.

During the autumns of 2006 and 2007, for both species and each substrate type, 25 seedlings were randomly selected for measurement of their above-ground height, root length, root collar diameter, above- and below-ground fresh weight.

Growth of one-year old and two-year-old seedlings of both species differed depending on their substrate. The application of a mycorrhizal inoculum positively affected seedling establishment, since the best height growth and largest seedlings of both species were grown on substrate (4). The growth of one-year-old fir seedlings in the 'old' peat and sawdust mixture (2) was similar to those seedlings grown on the turf substrate (3). Root:shoot allocation differed among the substrates. In fir, root:shoot allocation was approximately equivalent at 1:0.9, whereas for beech it was 1:2 in one-year old seedlings and 1:1.5 in two-year old seedlings.

Key words: substrate, peat, sawdust, seedling quality, container seedling, *Hebeloma crustuliniforme*

1. Introduction and aim of the study

With the development of plant production under controlled conditions, demand for substrates with very specific properties tailored to the needs of growing plants has increased. Even the most fertile mineral soil is not suitable for container-grown nursery seedlings. This is due to different factors affecting the conditions for optimal growth of seedlings' root systems (Strojny 2003).

The origin of growing seedlings in containers reaches back to the nineteenth century, mainly in horticultural production. First, pots were filled with mineral soil to which compost was added, and then, substrates consisting of different components, such as peat, mulch, shredded bark and pine cones, as well as conifer sawdust began to be used for the production base. Currently, the main component of the substrate for container nursery production is peat moss (sphagnum) with other components added to improve aeration and soil moisture properties, mainly perlite and vermiculite.

The finished product of nursery production substrates mixed from various components must be

Received 23 August 2012, accepted after revision 4 January 2013

homogenous. This also applies to the even distribution of fertiliser. If the components are inadequately mixed, the seedlings grown from the same batch of seeds may be of differentiated quality (Górka 2003).

Interest in the container production technology of forest tree seedlings is due to the increased area of revegetative and afforestation activities carried out in difficult soil and climatic conditions, such as after fires and environmental disasters, as well as in post-mining pits (Szabla, Pabian 2003; Khasa et al. 2005). Seedlings with a covered root system can be planted throughout the growing season. Experimental results in Scandinavia indicate a good effect for the production of container-grown spruce as regeneration material planted even in June and July (Helenius et al., 2002, 2005). Barzdajn (2010) obtained similar results in Poland with Scots pine, whose optimum planting time was found to be August. One of the centers where research is conducted on the use of new developments in growing seedlings in the covered root system is the Teaching and Research Station of the Department of Genetics, Seed and Forest Nursery in Krynica-Kopciowa (GSFN) (Faculty of Forestry, University of Agriculture in Krakow). Since the 1970s, research has been conducted on the use of different substrates and containers for nursery production. The result was the introduction of a peat-sawdust mixture to nursery practice, which is used also in the National Forests for the production of seedlings under controlled environmental conditions (Bałut et al., 1987, 1988).

This paper presents the results of research on the comparison of the influence of different substrates on the growth of seedlings of two major mountain forest species, namely silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.). The following substrates were used: a peat-sawdust substrate in two variants, differing in the length of use, a peat substrate mixed with perlite produced in the 'Nędza' nursery of the Rudy Raciborskie Forest District, one clean and the other a mycorrhizal enriched preparation containing *Hebeloma crustuliniforme* mycelium. The study evaluated the influence of the substrate used on the growth parameters for one-year old and two-year old fir and beech seedlings.

2. Materials and methods

The experiment was conducted at the experimental nursery of the Department of Genetics, Seed and Forest Nursery in Krynica-Kopciowa. The study began in the spring of 2006 and continued until the autumn of 2007. Styrofoam multi-pot seed trays were sown with stratified seeds harvested in the autumn of 2005. The seeds originated from the separated seed stand growing in the Krynica Experimental Forest Station (EFS) of the Powroźnik forest range section 114c (fir) and in the Jaworze forest range of the Bielsko Forest District, section 187a (beech). The sown trays were placed in a plastic tent. Four variants of the production base were used for the container plantings of fir and beech seedlings.

– TTf-0 – peat-sawdust substrate, mixed in a 1:1 ratio, newly prepared,

– TTf-5 – peat-sawdust substrate, mixed in a 1:1 ratio, used for five production periods (two years for the production of beech, three for fir)

– Tf – peat + perlite substrate produced in the 'Nędza' nursery of the Rudy Raciborskie Forest District,

– Tf+HC – peat + perlite substrate (as above), enriched with a preparation of the fungus *Hebeloma crustuliniforme*.

Each variant of the substrate was used to fill eighteen polystyrene multi-pot trays which were randomly divided into three repetitions. All the substrates were initially enriched with Azofoska fertiliser in a dose of 2 kg×m^{-3}. Additional foliar fertilisation was not applied during the growing season.

The seedling material was grown in polystyrene containers manufactured by 'Marbet' in Bielsko-Biała. The dimensions of the nursery trays were 650×315×180 mm. Each tray held 53 tapered cells (pots), each with a capacity of 285 cm^3. A single pot was equipped with four long vertical projections (called ribs) to prevent the roots from wrapping around the perimeter walls. The trays were made of expandable polystyrene (styrofoam) with a density of 38 g×dm^{-3}.

A mycorrhizal biological agent was used, consisting of a live, vegetative mycelium *Hebeloma crustuliniforme* – known as poison pie or fairy cakes, produced in the container nursery of the Rudy Raciborskie Forest District. The mycorrhizal agent was mixed with the substrate in an amount of 2,5% of its volume (Kowalski 2008) immediately prior to filling the multi-pots and sowing the seeds. The seedlings were placed in a plastic tent over a period of about 10 weeks during the growing season, i.e. until mid-July.

In the autumn of 2006 and 2007, 25 seedlings of each species were randomly chosen from each substrate variant and repetition for laboratory analysis. Above-ground height, length of the root system (accurate to

1 mm) and the thickness of the root collar (with an accuracy of 0,01 mm) were measured for each seedling. The seedlings' root system was thoroughly cleaned of the remaining substrate material under running water. After 24 hours, the fresh mass was measured for the above-ground parts and roots, and then, after a month of drying at room temperature (22–24°C), the dry mass was measured. Single seedlings were weighed to the nearest 0,001 g using an electronic scale. The fresh weight of two-year old seedlings was not analysed because too much time had elapsed from the time the specimens were collected.

For each substrate variant, average values were determined of the seedlings' characteristics, namely, the above-ground height (AGH), root system length (RSL), root collar diameter (RCD), above-ground mass of individual seedlings (AGM), including the shoot with its assimilation apparatus, root system mass (RSM) and the mass of the whole seedling (WSM).

The assessment was carried out separately for each species and the age and type of substrate used. The measurement data was analysed using the two-way analysis of variance with interaction; homogeneous groups were determined using the least significant difference test. Letters were used in the results' tables to denote the homogenous groups, i.e., the average values belonging to a given homogeneous group were denoted with the same letter. Computations were performed using STATISTICA 9.0 according to procedures for "General Linear Models", with the level of significance for $p \leq 0{,}01$.

Based on seedling growth parameters (height, root collar thickness and length of the root system) quality classes were specified (I, II and unclassified) for the fir and beech nursery specimens according to the requirements of Polish Standard PN-R-67025. If the value of one of the assessed features did not meet the requirements of class I, the seedling was qualified as class II or unclassified. Then, the percentage of seedlings in specific classes was calculated. The standard does not anticipate the quality assessment of the Beech 2/0k assortment, so for comparison purposes, border values increased by 20% were adopted for the classes of the Beech 2/0 assortment.

3. Results

The effect of the substrate on seedling parameters

Table 1 presents the results of the assessed growth characteristics and weight parameters of the one- and two-year old nursery specimens produced in polystyrene containers.

Fir (1/0k). Assessment of the growth characteristics of one-year old firs showed the highest amount of above-ground height (AGH), equal to 5,5 cm, in plants grown on the peat substrate with the mycorrhizal application. In terms of the length of the root system, (RSL) and the root collar thickness (RCD), the dominant seedlings were those grown in the peat-sawdust substrate used 5 times – TTf-5, reaching 18,4 cm and 1,77 mm respectively. One-year old fir seedlings grown in new peat substrate TTf-0 had the least values for all assessed growth characteristics (Table 1).

In terms of weight parameters, firs grown in the peat substrate with the *Hebeloma crustuliniforme* fungus stand out, as they obtained the highest values for the dry weight of the above-ground parts (0,252 g), the root system (0,252 g) and whole seedlings (0,504 g). The firs with the smallest mass were those grown in the new peat-sawdust substrate (AGM = 0,184 g, RSM = 0,164 g, WSM = 0,348 g). The same trend was observed for fresh weight. The highest values of fresh weight growth traits were found for the Tf + Hc substrate, and the lowest for the new peat-sawdust substrate. The values of the fresh weight of one-year old fir seedlings from the used peat-sawdust substrate (TTf-5) and the peat substrate (Tf) had comparable values (Table 1).

Fir (2/0k). Two-year old fir trees from the substrate treated with the mycorrhizal fungus *H. crustuliniforme* maintained the advantage in terms of the values of growth characteristics over plants grown in the remaining substrate variants (AGH = 13,4 cm and RCD = 3,85 mm). Only the length of the root system (RSL) did not differ much from seedlings grown in the peat substrate (30,6 cm). As in the case of the one-year olds, the lowest values of growth characteristics were similarly exhibited by seedlings grown in the new peat-sawdust substrate (AGL = 9,7 cm, RSL = 27,5 cm, RCD = 3,13 mm) (Table 1).

The lowest average value of dry mass for two-year old fir seedlings was found for seedlings growing in the new peat-sawdust substrate (1,331 g). The heaviest were clearly those growing in the peat substrate with the added mycorrhizal fungus (2,351 g). The dry weight

Table 1. Growth and weight parameters of fir and beech seedlings produced in foam container with identification of homogeneous groups (NIR test, p=0,05)

Substratum variant	Assortment	Growth parameters			Weight parameters					
					air dry mass			fresh mass		
		WCN (cm)	DSK (cm)	GSK (mm)	MCN (g)	MSK (g)	MCS (g)	MCN (g)	MSK (g)	MCS (g)
Fir										
TTf-0	1/0k	4,8^{a}	17,7^{a}	1,45^{a}	0,184^{a}	0,164^{a}	0,348^{a}	0,192^{a}	0,172^{a}	0,364^{a}
TTf-5		5,2^{b}	18,4^{a}	1,77^{b}	0,247^{b}	0,239^{b}	0,486^{b}	0,261^{b}	0,258^{b}	0,519^{b}
Tf		5,4^{bc}	18,0^{a}	1,77^{b}	0,244^{b}	0,235^{b}	0,478^{b}	0,256^{b}	0,251^{b}	0,507^{b}
Tf+Hc		5,5^{c}	18,3^{a}	1,76^{b}	0,252^{b}	0,252^{b}	0,504^{b}	0,266^{b}	0,262^{b}	0,527^{b}
TTf-0	2/0k	9,7^{a}	27,5^{a}	3,13^{a}	0,701^{a}	0,630^{a}	1,331^{a}		not measured	
TTf-5		11,8^{b}	30,3^{b}	3,52^{b}	0,994^{b}	0,886^{b}	1,889^{b}			
Tf		12,1^{b}	30,6^{b}	3,63^{b}	1,065^{b}	0,885^{b}	1,951^{b}			
Tf+Hc		13,4^{c}	29,5^{ab}	3,85^{c}	1,261^{c}	1,090^{c}	2,351^{c}			
Beech										
TTf-0	1/0k	16,4^{a}	20,7^{a}	4,54^{a}	0,712^{a}	2,126^{a}	2,838^{a}	1,028^{a}	2,997^{a}	4,025^{a}
TTf-5		17,5^{b}	18,6^{b}	5,06^{b}	0,950^{b}	1,847^{b}	2,797^{a}	1,427^{b}	2,680^{a}	4,107^{a}
Tf		18,4^{c}	18,0^{b}	5,37^{c}	1,140^{c}	2,151^{a}	3,291^{b}	1,719^{c}	3,394^{b}	5,173^{b}
Tf+Hc		19,2^{d}	18,1^{b}	5,55^{c}	1,215^{c}	2,317^{a}	3,531^{b}	1,860^{d}	3,650^{b}	5,510^{b}
TTf-0	2/0k	24,5^{ab}	22,3^{a}	5,35^{a}	2,670^{a}	4,320^{a}	6,990^{a}		not measured	
TTf-5		23,1^{a}	22,1^{a}	5,98^{b}	2,771^{a}	4,214^{a}	6,985^{a}			
Tf		25,4^{b}	20,4^{b}	6,24^{bc}	3,269^{a}	4,402^{a}	7,671^{a}			
Tf+Hc		27,6^{c}	21,8^{a}	6,56^{c}	4,096^{b}	5,243^{b}	9,340^{b}			

Explanation of symbols: WCN – height of the aboveground part, DSK – length of the root system, GSK – root collar diameter, MCN – weight of the aboveground part, MSK – weight of the root system, MCS – mass of the entire seedling; ground variants: TTf-0 – new sawdust-peat substrate, TTf-5 – five-year-old sawdust-peat substrate, Tf – peat with perlite, Tf+Hc – peat with vermiculite and *Hebeloma crustuliniforme*, a, b, c, d – homogeneous groups

of two-year old container-grown fir seedlings from the TTf-5 substrate was less than those grown in the peat substrate (Tf) (Table 1).

Beech (1/0k). The highest growth characteristics (AGH and RCD) were attained by plants grown in the peat substrate enriched with the mycorrhizal fungus (respectively 19,2 cm and 5,5 mm), while the least growth was found for those from the new peat-sawdust substrate (16,4 cm and 4,54 mm). TTf-0 grown seedlings dominated in root system length (20,7 cm). The shortest beech tree roots developed in the peat substrate (18,0 cm).

The highest dry and fresh mass of the studied traits were found in seedlings grown in the substrate with the added mycorrhizal fungus. In contrast, the lowest weight of above-ground seedling parts was found for those grown in the new substrate (TTf-0). The minimum value for root system mass (RS) was recorded in seedlings from the used substrate (dry weight = 1,847 g, fresh weight = 2,680 g) (Table 1).

Beech (2/0k). Container-grown beech seedlings with high values of AGH and RCD were grown on the substrate with the mycorrhizal fungus (27,6 cm and 6,56 mm respectively), while the longest root system (RSL), equal to 22,3 cm, was obtained from the seedlings grown in the TTf-0 substrate (Table 1).

Two-year old beech seedlings grown in the mycorrhizal supplemented substrate dominated in the results obtained for dry mass of the assessed morphological elements. The lowest mass of the above-ground part of the seedlings (2,670 g) were from the TTf-0 substrate, while the lowest mass of the root system (4,214 g) was found in the seedlings from the TTf-5 substrate – peat-sawdust after five years of use (Table 1).

The quality of seedlings

The highest quality seedlings were the one-year old and two-year old firs grown on the peat substrate with the mycorrhizal fungus *H. crustuliniforme*, of which 90,7% and 89,3% were assigned to Class I. After the second year, only 38,7% of fir seedlings grown in the new peat-sawdust substrate were classified to Class I. Regardless of the substrate used, only a small percentage of seedlings (1,3%) were assigned to the unclassified status (Table 2).

Container-grown beech seedlings (1/0k, 2/0k) were of poorer quality compared to firs. The best growth characteristics being analysed were found in beech seedlings grown in the peat substrate with added *H. crustuliniforme* fungus (Class I + II, 9,3% and 20% respectively). In both age groups, the lowest quality seedlings were from the TTf-5 variant substrate. Almost all the beeches (97,3% and 94,7%) from this substrate were unclassified (Table 2). It should be noted, however, that such a low proportion of class I and II seedlings was significantly impacted by root system length, which was limited by the height and volume of the polystyrene multi-pots. A quality assessment simulation omitting this parameter showed that the proportion of good quality plants (classes I + II) significantly increased, even up to 70% in the case of the peat substrate with the added mycorrhizal fungus.

The proportion between above-ground and underground parts

The proportion of the above-ground length of the silver fir to the length of its root system averaged 1:3.5 to 1:2.5 for the one-year old and two-year old seedlings respectively. The proportion of the dry mass of these features was close to 1 (average of 1:0.95), regardless of the age of the seedling and substrate variant used.

The opposite trend was found for beech, whose average above-ground height was comparable to the length of its root system - 1:1.1 to 1:0.9 for the one-year old and two-year old seedlings respectively. However, the dry mass analysis showed an average of almost two times greater biomass invested in the root system of a one-year old beech. Only in the case of the new peat-sawdust substrate (TTf-0) was the relative ratio 1:3. Such a large difference was not found for the two-year old seedlings. The relative ratio of the above-ground plant mass to the root system mass was similar for all variants of the substrate, close to the average level of 1:1.5 (Fig. 1).

4. Discussion

Container plant production is a new challenge for forest management. Research results and publications in the professional literature on this topic are few, and mainly refer to pine (Khasa et al. 2005; Dominguez-

Table 2. Percentage of quality classes fir and beech seedlings, produced on different substrates in styrofoam containers (explanation of symbols – see Table 1)

Quality	Seedling production symbol							
	1/0k				2/0k			
	substratum variant							
	TTf-0	TTf-5	Tf	Tf+Hc	TTf-0	TTf-5	Tf	Tf+Hc
	Fir							
First class	85,4	85,3	82,7	90,7	38,7	77,4	73,4	89,3
Second class	13,3	14,7	17,3	9,3	61,3	21,3	25,3	10,7
Classless	1,3	0,0	0,0	0,0	0,0	1,3	1,3	0,0
	Beech							
First class	1,3	0,0	0,0	1,3	0,0	0,0	0,0	2,7
Second class	8,0	2,7	10,7	8,0	9,3	5,3	6,7	17,3
Classless	90,7	97,3	89,3	90,7	90,7	94,7	93,3	80,0

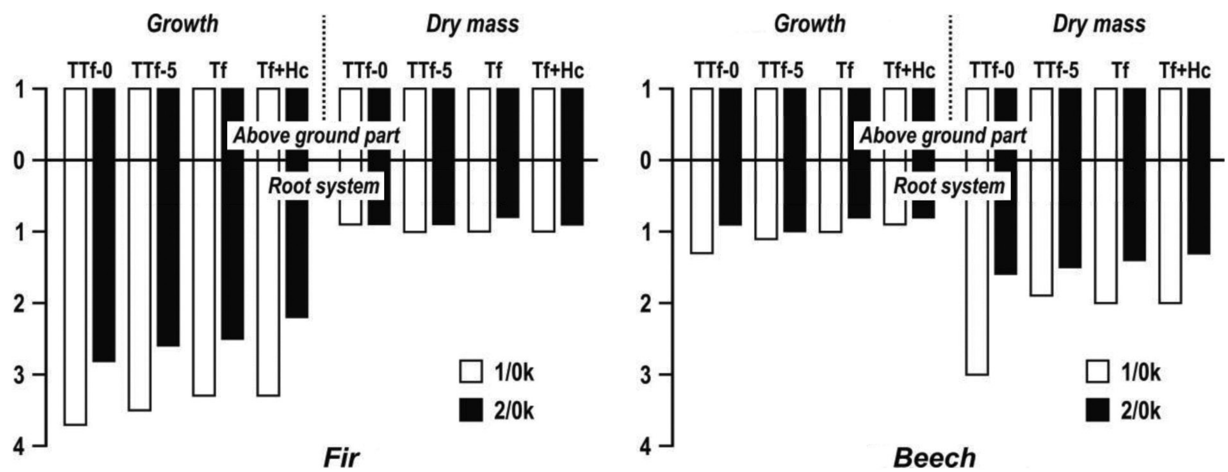

Figure 1. The relative proportion of length and dry mass of the aboveground part to the root system of fir and beech seedlings produced in foam containers (explanation of symbols – see Table 1)

Lerena 2006; Öner, Eren 2007; Barzdajn 2010; Pinto et al. 2011) and spruce (Helenius et al., 2002, 2005). There is little information detailing the production of fir seedlings in containers. This species began to be grown on a commercial scale in 2002 in the 'Kolonia' container nursery of the Oleszyce Forest District (Szabla, Pabian 2003). A three-year production cycle is used, which includes two years of growing seedlings in the ground at the nursery and transplanting them in their third year to styrofoam containers with cells of a 300 cm^3 volume. Similar nursery trays were used in the experiment. Fir seedlings were not transplanting, but seeds were manually sown into the cells of the multi-pot trays. Growing beech in containers for forestry management purposes occurs only over a one-year cycle and uses containers with cells of 250–300 cm^3 volume. Experience to date has shown the need to sow seeds of sprouted nuts just below the surface of the substrate, and to maintain the germinating seedlings for 5 to 8 weeks in a plastic tent under controlled conditions. After the risk of frost has passed, the trays are transferred to the outdoors (Szabla, Pabian 2003).

The study results show a statistically significant impact of the substrate variant on the quality of fir and beech seedlings. Fir seedlings produced on the older peat-sawdust substrate used five times and untreated with the mycorrhizal application exhibited good breeding qualities. The least favorable substrate for firs grown in the two-year production cycle was new peat-sawdust substrate, but regardless of the species and age of planting, seedlings produced on peat substrates with the addition of the *Hebeloma crustuliniforme* fungus were found to have the best quality breeding characteristics.

The results confirmed previous studies of Balut et al. (1987, 1988) and Sabor (1999), who found that the most suitable substrate for the growth of beech is a newly prepared peat-sawdust substrate with favorable aeration qualities. According to these authors, the structure of the substrate is essential for the good growth of this species' seedlings. In turn, this substrate is not suitable for the production of fir. Much better quality results are achieved by growing fir on a substrate that has been used for several years and has a more compact structure with the presence of natural mycorrhizae. Stępniewska (2004) found that the age of the production substrate affects the formation of mycorrhizae in fir trees, and seedlings better equipped with mycorrhizae can be obtained with older peat-sawdust substrates, previously used for producing the trees. At the same time, she noted that seedlings with mycorrhizae tended to have poorer quality parameters, in contrast to the present study, where firs grown in the mycorrhizal treated substrate had the best results for each of the analysed traits. This difference was even greater in the two-year old seedlings, with average values forming a separate, homogeneous group. Buraczyk et al. (2012) also analysed the effect of mycorrhizal fungi on Scots pine seedlings growing in different substrates, showing the interaction between the type of soil and use of mycorrhizal fungi, which significantly influenced the growth parameters of the seedlings produced.

An important element in container production is the assessment of the quality of the planted specimens, performed on the basis of measuring biometric features as set forth in the Polish Standard PN-R-67025. Aleksandrowicz-Trzcińska (2003) proposed extending the quality classification of seedlings to include the occurrence of mycorrhizae on the roots and determining their viability by measuring the electrical resistance of the shoot's phloem tissues. The author showed that assessing the quality of the seedling by using three methods simultaneously fully characterises the condition of the plants and their usefulness for production. According to Mikułowski and Kloskowski (1999), the quality of seedlings produced in containers depends to a large extent on the date of sowing. Early spring sowing extending the growing season increases the size of seedlings, but at the same time, it also increases the percentage of root system deformations. This issue has not been the subject of detailed analysis in the present study. Only a small number of beech seedlings were noted with a "pipe-like" bend in the root collar.

The good quality of the fir found in this study indicates the possibility of growing better seedlings using the container method in comparison with conventional production. This is confirmed by research conducted by Öner and Eren (2007), which showed better parameters of nursery-grown *P. sylvestris* and *P. nigra* using containarised compared to bare root plants. A similar relationship was observed by Thiffault et al. (2003) for container-grown spruce. They also formulated the thesis that in the first year after planting, transplanting shock caused by the lack of water is lower in plants grown using the bare root system. These seedlings' roots have a higher water potential, but three years after planting, the seedlings grown in containers showed better growth as compared to those grown in the ground. The effects of the type of nursery technologies used on the growth of firs are also presented by the research of Barzdajn and Kuczkowski (2010). According to these authors, peat pellet produced seedlings, showed no qualitative advantage over bare-root seedlings even after several years of growth in the nursery. Alm (1983) obtained the opposite results, observing greater stress in plants grown in the ground nursery. Transplant shock was manifested by a reduction of the root system and a greater degree of damage than observed in container-grown plants. In terms of seedling adaptation during production, Haase and Rose (1993) found that seedlings with a larger volume of roots adapted better during production and better withstood the effects of transplant shock in their analysis of the root system of *Pseudotsuga menziesii*.

In nursery production, an important task is to maintain the structural proportion of plants and attention should also be paid to their mass. According to Janssen et al. (1990), the growth and dry mass of seedlings grown under controlled conditions show a close relationship to the height and mass of trees at the age of 20-30 years.

In the present study, the root systems with the most mass developed in the fir and beech seedlings produced in the substrate with the mycorrhizal fungus *H. crustuliniforme*. If this substrate is removed from the analysis, the largest root mass was found for the fir grown in the peat-sawdust substrate already used five times, whereas in the case of beech seedlings, those grown in the new peat-sawdust and only peat substrates.

A characteristic proportion of the shoot's dry mass with its assimilation apparatus to root system mass was also observed in the seedlings of both species. The proportion of the above-ground dry mass to the underground mass in one-year old and two-year old firs for each substrate variant was similar, approximately 1:0.9. The proportions were more varied for beech. It was 1:2 in one-year old beech seedlings, except for those grown in the new peat-sawdust substrate (1:3), whereas for two-year old seedlings, the proportion decreased to 1:1.5 for the peat-sawdust substrates and 1:1.3 for only peat.

Choosing the most appropriate container for the species and assortment being grown is also an important factor in container-grown production. Styrofoam containers are mainly used for deciduous trees, as well as fir and spruce among the evergreens (Szabla, Pabian 2003). An important advantage of using styrofoam containers, especially in mountainous areas, is their better thermal insulation compared to traditional, thin-walled plastic containers (Banach, Sabor 1997; Banach 1999). These issues were analysed by Pinto et al. (2011), who showed that the type of container used significantly affects the survival and growth of *Pinus ponderosa* seedlings grown in different trophic and moisture conditions. The studies of Dominguez-Lereny et al. (2006) also indicate a positive correlation between the size of the container and the height and biomass of leaves and roots of *Pinus pinea* seedlings. The authors found that containers with a volume of 300-400 cm^3 were optimal for the growth of this species. According Moorhead (1981), seedling height increases as the pot size grows, but this does not change the diameter of the stem and root biomass. The presented research shows that the volume of the cells in the Robin-type styrofoam trays ensures the appropriate growth of firs. Container-grown seedlings attained the proper quality parameters and over 70% of them were categorised to class I. In the case of beech, however, two-year old container-grown seedlings were deemed of lesser quality, which may have resulted from an inappropriate system of irrigation used in the nursery (no mobile ramp) and low-volume root ball.

Most of the research cited and the results obtained in the present study suggest the desirability of the container method of producing seedlings. The advantages of this technology include the satisfactory growth characteristics of the plant stock grown and high crop success in difficult environmental conditions for regeneration, which is associated with lower costs incurred for subsequent specimen replacement activities and tending the crop (Szabla 2004, 2009).

5. Conclusions

Based on the study of one-and two-year old fir and beech seedlings produced in various substrates, the following conclusions can be formulated:

1) The substrate significantly influences the growth and characteristics of the analysed parameters of one-year and two-year old fir and beech seedlings.

2) Regardless of species or age, the best quality of the seedlings produced in containers was achieved with the peat substrates with the addition of the mycorrhizal fungus *Hebeloma crustuliniforme*. Comparable quality was achieved in the case of fir grown in the older peat-sawdust substrate used five times without the mycorrhizal fungus.

3) Specific ratios in the distribution of fir and beech seedling biomass were found to occur. The proportion of above-ground dry mass to that of the underground part regardless of substrate variant used was similar and amounted to approximately 1:0.9 for one-year old and two-year old fir. The proportions for beech were on average 1:2 for the one-year old seedlings and 1:1.5 for those that were two years old.

Acknowledgements

The study was carried out as part of the statutory activities of the Faculty of Forestry in Krakow (No DS-3405) funded by the Ministry of Science and Higher Education.

References

Aleksandrowicz-Trzcińska M. 2003. Ocena jakości hodowlanej dwuletnich sadzonek sosny zwyczajnej (*Pinus sylvestris*. L.) poddanych sterowanej mikoryzacji. *Sylwan*, 147 (2): 49–57.

Alm A.A. 1983. Black and white spruce planting in Minnesota: container vs. bareroot and fall vs. spring planting. *Forest Chronicle*, 59: 189–191.

Bałut S., Kulej M., Sabor J., Sobolewska K. 1987. Wpływ podłoży trocinowo-torfowych oraz rodzaju nawożenia na wzrost i jakość materiału sadzeniowego w namiotach foliowych. *Informator Regionalny Zakładu Upowszechniania Postępu AR w Krakowie*, 263: 3–34.

Bałut S., Kulej M., Sabor J., Sobolewska K., Wojtas R. 1988. Wpływ czasookresu użytkowania podłoży trocinowo-torfowych na ich bilans nawożeniowy oraz wzrost i jakość sadzonek produkowanych w kontrolowanych warunkach zewnętrznych. *Informator Regionalny Zakładu Upowszechniania Postępu AR w Krakowie*, 271: 121–130.

Banach J. 1999. Zastosowanie metod produkcji materiału szkółkarskiego z zakrytym systemem korzeniowym w warunkach górskich. *Sylwan*, 143 (1): 61–75.

Banach J., Sabor J. 1997. Nowe technologie produkcji sadzonek z zakrytym systemem korzeniowym. Biblioteczka leśniczego, 82. Warszawa, Wydawnictwo Świat

Barzdajn W. 2010. Wzrost uprawy sosny zwyczajnej (*Pinus sylvestris* L.) założonej przy użyciu sadzonek z bryłką i z nagim korzeniem w różnych terminach sadzenia. *Sylwan*, 154 (5): 312–322.

Barzdajn W., Kuczkowski K. 2010. Wzrost sztucznych odnowień jodły pospolitej *(Abies alba* Mili.) w różnych warunkach drzewostanowych i siedliskowych w Nadleśnictwie Szklarska Poręba. *Opera Corcontica*, 47 (Suppl. 1): 189–202.

Buraczyk W., Szeligowski H., Drozdowski S., Aleksandrowicz-Trzcińska M. 2012. Wpływ wilgotności i gatunku gleby na wzrost mikoryzowanych sadzonek sosny zwyczajnej (*Pinus sylvestris* L.). *Leśne Prace Badawcze*, 73 (1): 57–64.

Dominguez-Lerena S., Herrero Sierra N., Carrasco Manzano I., Ocańa Bueno L., Peńuelas Rubira J.L., Mexal J.G. 2006. Container characteristics influence *Pinus pinea* seedling development in the nursery and field. *Forest Ecology and Management*, 221: 63–71.

Górka W. 2003. Mieszanie i przechowywanie podłoży. *Szkółkarstwo,* 4.

Haase D.L., Rose R. 1993. Soil moisture stress induces transplant shock in stored and unstored 2+0 Douglas-fir seedlings of varying root volume. *Forest Science*, 39: 275–294.

Helenius, P., Luoranen, J., Rikala, R., Leinonen, K. 2002. Effect of drought on growth and mortality of actively growing Norway spruce container seedlings planted in summer. *Scandinavian Journal of Forest Research*, 17: 218–224.

Helenius, P., Luoranen, J., Rikala, R. 2005. Effect of preplanting drought on survival, growth and xylem water potential of actively growing *Picea abies* container seedlings. *Scandinavian Journal of Forest Research*, 20: 103–109.

Janssen A., Dromling I., Eriksson G., Norell L., Stener L-G. 1990. Retrospective early tests for growth in *Pinus sylvestris*. *Forest Tree Improvement*, 24: 115–122.

Khasa D.P., Fung M., Logan B. 2005. Early growth response of container-grown selected woody boreal seedlings in amended composite tailings and tailings sand. *Bioresource Technology*, 96: 857–864.

Kowalski S. 2008: Instrukcja użytkowania polskiego biopreparatu z grzybem mikoryzowym *H. crustuliniforme* wytwarzanego w laboratorium szczepionek mikoryzowych w LBG Kostrzyca. http://www.lbg.jgora.pl/zespoly/ZB/instrukcja.htm [15.03.2012].

Mikułowski M., Kłoskowska A.1999. Przyczynek do oceny wydajności siewu w szkółkach kontenerowych w aspekcie jakości sadzonek. *Sylwan,* 143(11): 57–67.

Moorhead, D. J. 1981. Container size and growth media influence early growth and survival of southern oaks in Mississippi, in: P.S. Johnson i H.E. Garrett "Workshop on seedling physiology and growth problems in oak planting". University of Missouri, Columbia, 6–7 listopada 1979 r., p. 20.

Öner N., Eren F. 2007. The comparisons between root collar diameter and height growth of black pine (*Pinus nigra* Arnold.) and Scots pine (*Pinus sylvestris* L.) seedlings in Bolu Forest Nursery. *Journal of Applied Biological Sciences*, 2 (1): 7–12.

Pinto J.R.,. Marshall J.D., Dumroese R.K., Davis A.S., Cobos D.R. 2011. Establishment and growth of container seedlings for reforestation: A function of stocktype and edaphic conditions. *Forest Ecology and Management,* 261: 1876–1884.

Sabor J. 1999. Możliwości zastosowania substratów trocinowo-torfowych do produkcji sadzonek w namiotach foliowych. *Sylwan*, 143 (1): 99–112.

Stępniewska H. 2004. Mikoryzy siewek jodły (*Abies alba* Mill.) hodowanych na substracie trocinowo-torfowym w szkółce Feleczyn w Nadleśnictwie Nawojowa. *Sylwan*, 148 (6): 10–17.

Strojny Z. 2003. Podłoże w pojemnikowej produkcji szkółkarskiej. *Szkółkarstwo*, 4.

Szabla K. 2004. Ekonomiczne uwarunkowania produkcji sadzonek z zakrytym systemem korzeniowym w szkółkach kontenerowych, in: Materiały seminarium szkółkarskiego „Možnosti použití sadebního materiálu z intenzivních školkařských technologií pro obnovu lesa", Opočno, 3–4 czerwca 2004 r., p. 74–79.

Szabla K. 2009. Hodowlane i ekonomiczne aspekty produkcji materiału sadzeniowego z zakrytym systemem korzeniowym poddanego zabiegowi sterowanej mikoryzacji. *Sylwan*, 153 (4): 253–259.

Szabla K., Pabian R., 2003. Szkółkarstwo kontenerowe. Nowe technologie i techniki w szkółkarstwie leśnym. Warszawa, Centrum Informacyjne Lasów Państwowych .

Thiffault N., Jobidon R., Munson A.D. 2003. Performance and physiology of large containerized and bare-root spruce seedlings in relation to scarification and competition in Québec (Canada). *Annals of Forest Science*, 60 (7): 645–655.

Translated by: Barbara Przybylska