Comparison of morphological and physiological parameters of the planting material of Norway spruce (*Picea abies* [L.] Karst.) from intensive nursery technologies with current bareroot plants

J. Leugner, A. Jurásek, J. Martincová

Forestry and Game Management Research Institute, Strnady, Opočno Research Station, Opočno, Czech Republic

ABSTRACT: High quality of planting material is an essential prerequisite for successful artificial forest regeneration. We carried out a detailed investigation aimed at differences between plantable bareroot and container plants of Norway spruce (*Picea abies* [L.] Karst.). Based on the results of this experiment, there exist marked differences in basic morphological traits between bareroot plants and plugs. The largest differences were observed in root collar diameter and root system volume. Differences in physiological quality (nutrient content, function of assimilatory organs) were also great. The results document that container seedlings of Norway spruce produced by intensive technology in controlled conditions of plastic greenhouses have very good predispositions for successful growth in difficult mountain conditions.

Keywords: plugs; bareroot transplants; containerized seedlings; morphological and physiological quality; Norway spruce

High quality of planting material is an essential requirement for successful artificial forest regeneration. Intensive technologies for the production of containerized seedlings and plants are increasingly used in the present nursery practices.

If all principles of these intensive greenhouse technologies are observed, it is possible to produce the seedlings that are several times superior by their morphological parameters to seedlings grown in the same period in outdoor conditions (in mineral soil). Positive features of these plants are lower transpiration (but root absorption is higher) and better primordia for further growth (a higher number of larger and better-developed buds), so their increment in the subsequent year may be higher. From the aspect of their survival rate seedlings produced in plastic greenhouses have at least as good a potential for further growth as seedlings grown by conventional technologies (Mauer 1999).

There are large differences in morphological and physiological quality between bareroot transplants and plants from intensive nursery technologies (plugs). They can markedly influence subsequent survival rate and growth in plantations, especially if they are planted in extreme mountain conditions.

McDonald (1991) reported a higher survival rate in container seedlings of various tree species compared to bareroot ones in all types of examined sites.

Many authors reported faster growth of container planting stock compared to bareroot transplants within several years after outplanting (Lokvenc 1975; Vyse 1981; Mattice 1982). However, if plugs were markedly smaller than bareroot transplants at the time of planting, height differences usually persisted for a long time after outplanting (Gardner 1982; Mattice 1982; Alm 1983; Duddles, Owston 1990; Wood 1990).

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In other experiments marked diameter growth in plugs was observed after outplanting compared to their height growth; in some spruce species e.g. Burdett et al. (1984) reported a reduction in the slenderness ratio of plugs within 3 years after outplanting to the values usually measured in bareroot transplants.

As for the weaker root systems of plugs in comparison with bareroot transplants Bernier et al. (1995) proved that after outplanting the boundary between the plug and the soil was much greater limitation for water and nutrient uptake than the root systems themselves. In a longer time interval it is potential resistance to drought in relation to the rate of formation of roots that penetrate outside from the root ball to the adjacent soil.

It follows from the above results that many specialized papers compared container and bareroot planting material with respect to the growth of established plantations. These comparisons provide rather unambiguous results, which corresponds to a high variability of used planting material and to great differences in natural conditions of sites where they are planted (Menes et al. 1996). This is the reason why we carried out a detailed investigation of differences between plantable bareroot and container plants of Norway spruce (*Picea abies* [L.] Karst.) in 2006. We also evaluated the growth of different types of planting material in the first years after outplanting to a mountain locality.

MATERIAL AND METHODS

Plantable plants of Norway spruce from the 8th forest altitudinal zone (mountain spruce forest zone) produced in the same forest nursery were used to evaluate differences between various types of planting material. Bareroot transplants grown by a conventional method (2 + 1) were compared with plugs (1cg + 1c: one year in plastic greenhouse and one year in container in the open air) – container plants of the same height produced by an intensive nursery technology.

In both types of planting material basic morphological characteristics (height, root collar diameter, length of the last increment and the volume of shoots and root systems) were measured for which the methodology of the accredited testing laboratory Nursery Control was used. Other traits were also measured for a more detailed evaluation: length of the longest branch, root system length, dry weight of branches and stem, dry weight of assimilatory organs, dry weight of root system. The number of branches growing on an annual shoot and older branches was determined. To evaluate the assimilatory organs needle density and average weight of one needle were determined; the latter characteristic was assessed in each plant at three 5 cm sections of annual shoots (one section on the terminal shoot and two sections on primary lateral branches).

The content of basic mineral elements in assimilatory organs was measured to evaluate the nutrient status and activity of root systems. Analyses were done in the Tomáš Laboratory in Opočno according to conventional methodology (mineralization with H_2SO_4/H_2O_2, determination of N, P, K, Ca and Mg). Mixed samples of needles from plants used for the evaluation of morphological traits were subjected to analyses.

Physiological evaluation was aimed at the state and function of the photosynthetic apparatus when various parameters of chlorophyll fluorescence were measured. An Imaging-PAM 2000 apparatus (Walz, Effeltrich, Germany) was used. The function of photosystem II (PSII) is the most sensitive indicator of environmental stresses in plants. Changes in PSII activity may be assessed in a rapid and non-destructive way by measuring chlorophyll fluorescence. Many studies accentuate the parameter Fv/Fm (maximum quantum yield of PSII photochemistry) which is in good correlation with the quantum efficiency of photosynthetic assimilation of CO_2 or development of O_2. This parameter provides information that may be related to the daily and seasonal fluctuation of photosynthesis, plant growth and dynamics of stands (Call et al. 1994).

The values of Fo (minimum fluorescence at all reaction centres of photosystem II when open) and Fm (maximum fluorescence of a sample adapted to darkness after illumination – all reaction centres are closed, photochemical processes have not been activated yet) were measured in needles adapted to darkness. Based on these values, the value Fv/Fm = (Fm – Fo)/Fm (maximum yield of photochemistry of a sample adapted to darkness) was calculated. Measuring light of the intensity 2 μmol/m^2/s and saturation impulse of the intensity 2,400 μmol/m^2/s for 800 ms were applied for these measurements.

The reaction of assimilatory organs to changing light intensity was determined in the same samples of needles. The intensity of photosynthetically active radiation (PAR) was increased from 0 to 1,580 μmol per m/s, the interval between the impulses of saturation light was 20 seconds. The evaluated parameter was the electron transport rate (ETR) indicating the velocity of the transport of electrons from photosystem II and their utilization for further processes of photosynthesis.

Table 1. Morphological traits of bareroot and container plants (plugs) of Norway spruce (*n* = 40)

Evaluated trait		Bareroot plants		Plugs		*t*-test	
		mean	S_x	mean	S_x	*t*	significance
Root collar diameter (mm)		6.8	1.363	5.4	0.703	5.568	**
Shoot height (cm)		30.2	4.910	30.7	3.933	–0.478	–
Length of the	last increment (cm)	16.5	3.950	22.7	3.320	–7.539	**
	longest branch (cm)	12.3	2.775	9.5	2.061	5.123	**
	root system (cm)	38.7	11.605	19.6	3.748	9.906	**
Number of	branches per annual shoot	2.6	3.533	8.3	3.056	–7.616	**
	older branches	13.2	4.051	6.3	2.168	9.533	**
Volume of	shoots (ml)	23.8	9.814	18.5	3.591	3.223	**
	root system (ml)	9.0	2.987	5.5	1.086	6.939	**
Root to shoot ratio		0.42	0.161	0.31	0.064	4.330	**
Dry weight of	shoots (g)	9.50	4.148	5.34	1.156	6.104	**
	root system (g)	4.10	1.586	1.78	0.366	9.037	**
	stem and branches (g)	5.21	2.310	2.83	0.620	6.311	**
	needles (g)	4.29	1.927	2.52	0.641	5.509	**

**Statistically significant differences on a 99% significance level ($p = 0.01$), – statistically insignificant differences

Two needles from annual shoots of randomly selected 5 plants from each variant (method of cultivation) were used for each measurement. Measurements were repeated 6 times.

In addition to the evaluation of the quality of plantable plants, the growth of a plantation established by similar planting material in mountain conditions was studied (Krkonoše Mts., research plot Nad Terexem, group of forest site types 8K2 – acid mountain spruce forest, management group 515 D10, altitude 1,140 m above sea level). Height and diameter growth was investigated within two years after planting. The health status of plants was determined in two years after planting as defoliation index and discoloration index (changes in needle colour). This evaluation was based on a scale used for the monitoring of forest condition (Monitoring 2004).

Significance of differences between mean values of compared parameters was evaluated by Student's *t*-test for unequal sample sizes to *p*-value 0.01 and 0.05.

RESULTS

Evaluation of plantable plants

Plants of approximately the same height of shoots (ca. 30 cm) were selected for the evaluation. All the other morphological traits were statistically significantly different between the compared types of planting material (bareroot transplants – plugs) (Table 1).

Container plants (plugs) were more slender (the height to root collar diameter ratio = 4.4 in bareroot

Table 2. Contents of basic mineral nutrients in needles of bareroot plants and plugs (%)

Variant	N	P	K	Ca	Mg
Bareroot plant	1.61	0.21	0.60	1.20	0.10
Plug	1.81	0.18	0.70	0.39	0.11
Optimum*	1.40–2.20	0.20–0.40	0.40–1.50	0.20–0.40	0.10–0.30

*According to Landis et al. (1993)

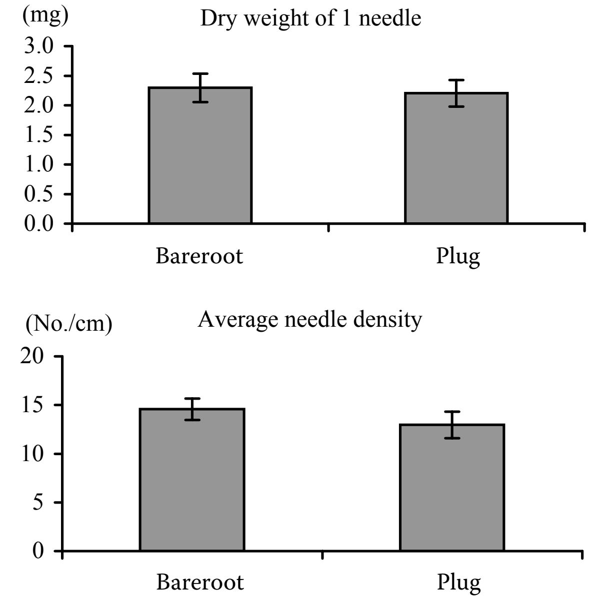

Fig. 1. Average needle density and average dry weight of one needle in plugs and bareroot plants. Vertical abscissas represent the confidence interval

plants and = 5.7 in plugs), they had shorter branches and a markedly lower volume of shoots and particularly of roots. These traits also imply a lower ratio of root to shoot volume. The dry weight of root systems and shoots, i.e. the dry weight of stem and branches and total dry weight of needles, was markedly lower in plugs.

The mean dry weight of one needle and needle density on branches and terminal shoots on 10 individuals from each variant were other evaluated traits. Plugs had lower needle density and lower dry weight of one needle, but the differences were statistically insignificant (Fig. 1).

The results of the analyses of basic nutrient content in needles (Table 2) indicated higher contents of N, K and Mg in plugs compared to bareroot transplants. On the other hand, they had lower contents of phosphorus and calcium. All elements were in an optimum range according to Landis et al. (1993), only the content of phosphorus in plugs was slightly lower and bareroot plants had a very high content of calcium.

Table 3. Characteristics of chlorophyll fluorescence

Variant		Fo	Fm	Fv/Fm
Container plants (plugs)	mean	0.072	0.315	0.761
	S_x	0.0147	0.0957	0.0321
	n	60	60	60
Bareroot plants	mean	0.101	0.475	0.783
	S_x	0.0193	0.0799	0.0175
	n	60	60	60
t		–9.252	–9.979	–4.751
Significance		**	**	**

**Mean p = 0.01

Table 3 shows the basic parameters of chlorophyll fluorescence measured after the illumination of needle samples adapted to darkness. These parameters illustrate the state and integrity of photosystem II (PSII) in chloroplasts. Significant differences between bareroot transplants and plugs were observed in all studied characteristics (Fo, Fm, Fv/Fm). Differences in the means calculated from all measurements between these types of plants were significant.

Light curves (changes in the photosynthetic transport of electrons at increasing radiation intensity) illustrate the utilization of light of different intensity. The evaluation of electron transport rate (ETR) from photosystems for their utilization in biochemical

Table 4. Growth parameters of planting material after outplanting in mountain conditions

	Bareroot plants	Plugs	*t*-test	Significance
Root collar 2004 (mm)	7.50	6.24	5.257	**
Root collar 2006 (mm)	9.24	9.25	–0.021	–
Height 2004 (cm)	31.59	30.99	0.600	–
Height increment 2005 (cm)	3.78	4.78	–2.813	**
Height 2006 (cm)	36.00	38.60	–2.336	*
Defoliation index 2006	0.283	0.239		
Discoloration index 2006	0.031	0.000		

*Mean p = 0.05, **mean p = 0.01, – statistically insignificant differences

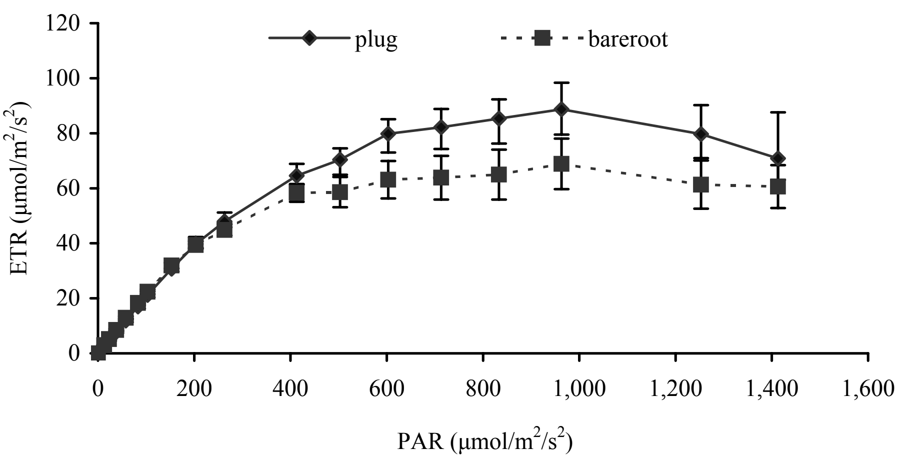

Fig. 2. Curves of electron transport rate (ETR) at increasing intensity of photosynthetically active radiation (PAR). Vertical abscissas represent the confidence interval

reactions is connected with the state of the photosynthetic apparatus and with photosynthetic rate. The comparison of average values of 5 plants showed higher ETR in container plants (plugs), especially for the mean values of photosynthetically active radiation (Fig. 2).The curves document the higher capacity of container plants (plugs) to utilize light energy, especially at higher intensities of incident radiation.

Growth evaluation after outplanting

Although the plugs produced in a forest nursery were weaker and had smaller root systems compared to the conventional bareroot transplants, their growth and health status were very good after outplanting to adverse mountain conditions (research plot Nad Terexem, 1,140 m a.s.l.). The root collar, which was significantly weaker in plugs at the time of outplanting in 2004, equalized with that of bareroot plants within two years. The shoot height that was identical in both types of planting material at the time of outplanting was significantly higher in plugs in two years after outplanting. The health status of container plants (plugs) was better if evaluated according to defoliation (defoliation index) and according to the presence of colour changes in needles (discoloration index) (Table 4).

DISCUSSION

The results of evaluating the morphological traits of plantable planting material showed significant differences between bareroot transplants and plants produced by intensive technologies (plugs) of Norway spruce; these results are in agreement with conclusions drawn by Seemen and Jaaratas (2005), who also confirmed significant differences in morphological quality between bareroot plants and container seedlings of Norway spruce. These differences are connected with a shorter time of plug growing (in our experiment two-year container plants were used in comparison with three-year bareroot transplanted plants) and with different type of growth of individuals when intensive growing methods are applied (growth stimulation in a plastic greenhouse, intensive fertilization, air pruning).

Marked differences were also determined in root system parameters. The root volume of plugs was substantially lower. It implies a lower ratio of root to shoot volume. Similar differences were described e.g. by Mauer (1999). The evaluation of the ratio of shoot to root dry weight provided comparable results.

The results of analyses of basic nutrient content in needles indicated comparable values in bareroot and container plants that were in an optimum range according to Landis et al. (1993) in most parameters, which documents a good function of root systems.

The method of determining chlorophyll fluorescence measures the fluorescence emitted by electrons in photosystem II that return from the high energy level to the state of lower energy. The character of such radiation may be interpreted as a barometer of the function of photosynthetic mechanism (Ritchie, Landis 2005). The values obtained by measurement of rapid changes in fluorescence after the illumination of needle samples adapted to darkness illustrate the state and integrity of photosystem II in chloroplasts. The evaluation of chlorophyll fluorescence has found a broad application in physiological and ecological research. This method may provide data on the capacity of plants to tolerate environmental stresses and data showing to what extent these stresses cause damage to the photosynthetic apparatus (Maxwell, Johnson 2000).

Even though the values of the maximal quantum yield of PSII (Fv/Fm) we recorded in this study in bareroot and container plants were different from each other, they were in the range of 0.75 to 0.83 reported as a normal range in trees of the temperate zone in the growing season (Čaňová 2002; Mohammed et al. 2003; Lichtenthaler et al. 2005). They indicate a good state of the photosynthetic apparatus in both types of evaluated plants.

The evaluation of growth parameters after outplanting to a mountain locality showed vigorous diameter growth in individuals coming from plugs; these results confirm the findings of Burdett et al. (1984) about the very intensive diameter growth of container seedlings of spruce. The initial statistically highly significant differences in root collar diameter equalized within two years. The height increment measured in 2005 was also significantly higher than in bareroot plants. The evaluation of health status (defoliation and discoloration index) documents the better health status of individuals from plugs compared to bareroot plants.

CONCLUSION

Based on the results of this experiment, there exist marked differences in basic morphological traits between bareroot transplants and plugs. The largest differences were observed in root collar diameter and root system volume. Differences in physiological quality (nutrient content, function of assimilatory organs) were also great. However, the growth of plugs, especially diameter growth, was resumed quickly after outplanting. The initial significant differences equalized within two years of growth in a mountain area and the diameter of the root collar of plugs was equal to that of bareroot plants.

The results document that container seedlings of Norway spruce produced by intensive technology in controlled conditions of plastic greenhouses have very good predispositions for successful growth in difficult mountain conditions. They are able to compensate the initial handicap of weaker stem and root systems within a short time. Their increased sensitivity to stem deformations and breaks caused by their high ratio of height to stem diameter may appear as a potential risk. But no such damage was observed in the extreme conditions of research plot.

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Porovnání morfologických a fyziologických parametrů sadebního materiálu smrku ztepilého (*Picea abies* [L.] Karst.) z intenzivních školkařských technologií s běžnými prostokořennými sazenicemi

ABSTRAKT: Vysoká kvality sadebního materiálu je nezbytným předpokladem pro úspěšnou umělou obnovu lesa. Zaměřili jsme se na detailní šetření rozdílů mezi výsadbyschopnými prostokořennými a krytokořennými sazenicemi smrku ztepilého. Na základě výsledků tohoto experimentu lze konstatovat, že mezi prostokořennými sazenicemi a plugy jsou výrazné rozdíly v základních morfologických znacích. Největší rozdíly byly zjištěny v tloušťce kořenového krčku a objemu kořenového systému. Výrazné rozdíly byly zjištěny i ve fyziologické kvalitě (obsah živin, funkčnost asimilačního aparátu). Výsledky ukázaly, že krytokořenné semenáčky smrku ztepilého pěstované intenzivní technologií v řízených podmínkách fóliových krytů mají velmi dobré předpoklady pro úspěšný růst i v náročných horských podmínkách.

Klíčová slova: plugy; prostokořenné sazenice; krytokořenné sazenice; morfologické a fyziologické parametry; smrk ztepilý

Corresponding author:

Ing. Jan Leugner, Výzkumný ústav lesního hospodářství a myslivosti, v.v.i., Strnady, Výzkumná stanice Opočno, Na Olivě 550, 517 73 Opočno, Česká republika
tel.: + 420 494 668 392, fax: + 420 494 668 393, e-mail: leugner@vulhmop.cz