Effect of desiccation on the root system of Norway spruce (*Picea abies* [L.] Karst.) seedlings and a possibility of using hydrogel STOCKOSORB® for its protection

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ABSTRACT: The aims of this study were: 1. to determine the effect of desiccation treatment on the physiological quality of Norway spruce (*Picea abies* [L.] Karst.) seedlings by measurements of electrolyte leakage from the root system; b) to test the use of hydrogel STOCKOSORB® for protection of the root system of spruce seedlings during their transplanting. The results showed that desiccation treatment significantly affected the rate of electrolyte leakage (34% leakage for control seedlings and 53% in contrast with seedlings after 5 hours of desiccation). Likewise, significant differences were found in height and root collar increments after the first vegetation period that decreased with the duration of desiccation treatment. The values of electrolyte leakage also increased with the duration of desiccation treatment for seedlings treated with hydrogel. On the other hand, the rate of electrolyte leakage was lower after 5 hours of stress factor than in untreated seedlings. The height and root collar increments were higher in seedlings treated with hydrogel for all variants. The obtained results showed a possibility of using the measurement of electrolyte leakage from the root system to determine the physiological quality of Norway spruce seedlings. The rate of electrolyte leakage over 40% signals the physiological damage to the root system of spruce seedlings. Next, the results confirmed the need of protection of seedling roots during handling. The seedlings without hydrogel had 35% height and 26% root collar diameter increment after two-hour desiccation stress. On the other hand, the same seedlings with STOCKOSORB had 42% height and 48% root collar increment.

Keywords: desiccation; electrolyte leakage; hydrogel STOCKOSORB®; root system; spruce seedlings

Artificial regeneration consists of different stages (forest nursery, handling and transporting of planting stock, short-term storage, planting). It is needful for successful reforestation to harmonize these stages and to prevent the effect of stress factors on planting stock.

The basis of successful reforestation programs is in a forest nursery. The planting stock for reforestation has to verify qualitative marks. Generally, the plant quality is a complex of genetic, morphological and physiological traits. The genetic quality of planting stock must be ensured by the use of proper seed and plants.

Morphological quality is affected by the methods of planting stock raising in a forest nursery. Transplanting is a very standard operation in nursery production. The aim of this operation is to support the root system growth (adequate proportion of fine roots).

Seedlings must be protected against sunshine, wind and heat during transplanting operations. These environmental factors could cause physiological damage to seedlings (mainly to the root system). Therefore work organization during seedling handling is very important (lifting of seedlings directly before transplanting; transplanting under cold and calm weather; mechanical control of seedlings, etc.). Nevertheless, there could occur seedling failures caused by physiological damage. Unfortunately, physiological damage is scarcely detected by visual inspection (McEvoy, McKay 1997) and the determination of this physiological damage of planting stock is very time consuming (Martincová, Nárovcová 2001).

Therefore, researchers look for new methods of determination of physiological damage to planting stock and of increasing of planting stock survival.

One of the solutions for better adaptability of plants after transplanting is the use of hydrogels (Jurásek 2001; Puhlová, Šmelková 1998; Roldan et al. 1996; Salaš et al. 1996; Hüttermann et al. 1999; Woodhouse, Johnson 1991, etc.).

Currently, the product Agricol is used for the root protection of forest planting stock in Slovakia. This hydrogel belongs to a group of sodium alginate. The positive effect of Agricol application on survival was reported by Chalupa (1977), Dimplmeier (1969). The hydrogel of this group passively protect the root system of planting stock during handling and transporting.

In the last years, a new generation of hydrogels has been developed, highly cross-linked polyacrylamides with 40% of the amides hydrolyzed to carboxylic groups. According to Bouranis (1995) these hydrogels are able to absorb and store up to 400 times their own weight of water, and therefore they reduce the water stress for trees. These hydrogels are frequently used for afforestation in semi-arid areas (ROLDAN et al. 1996; TOGNETTI et al. 1997). On the other hand, there is little available information about the use of these hydrogels in the environmental conditions in Central Europe.

The aims of this study were:

– to determine the effect of desiccation on the physiological quality of spruce seedlings by measurements of electrolyte leakage from the root system,
– to test the use of these hydrogels STOCKOSORB® for protection of the root system of spruce seedlings during transplanting.

MATERIAL AND METHODS

1. Assessment of desiccation effect on the physiological quality of seedlings

Norway spruce (*Picea abies* [L]. Karst.) three-year bare-rooted seedlings that were cultivated in a forest nursery of Forest Research Institute in Zvolen were used in this study.

On the 25th March 2002 the seedlings were lifted from nursery beds and biometrical traits were measured (height 19.2 cm; diameter of root collar 3.2 mm). The seedlings did not show any visual marks of physiological activity (bud break). Directly after lifting, a desiccation test was carried out. The test seedlings were placed outdoors on the concrete ground and exposed to desiccation for 2, 4 and 5 hours. The air temperature was 17°C, sunshine.

After the artificial stress the samples (from each stressed variant + control variant, 15 seedlings were used) were prepared for measurements of electrolyte leakage from the root system (REL). The electrolyte leakage was assessed according to the method described by SARVAŠ (2002).

Next, other 10 seedlings from each variant were planted into containers after the stress treatment (0.7 L volume – 30% of peat, 70% of soil). The containers were placed on a nursery bed and irrigated regularly. After the first vegetation period (on 13th September) the survival, height and diameter increment of root collar were calculated:

$$\textit{height/diameter increment (\%)} = \frac{\textit{autumn height/diameter} - \textit{spring height/diameter}}{\textit{spring height/diameter}}$$

2. Assessment of STOCKOSOR® AGRO application for the protection of spruce seedling roots

Forest nursery of Forest Research Institute

Seedlings from the same nursery bed were used as that for the assessment of desiccation effect on the physiological quality of spruce seedlings. After seedling lifting they were treated with the hydrogel STOCKOSORB® (70 g of hydrogel granules was stirred into 10 litres of water and the root dip was made after 10 minutes).

After the application of hydrogel to the root system a desiccation test was carried out followed by measurements of electrolyte leakage and planting into containers (the same procedure as in the previous test). The survival, height and diameter increment of root collar were calculated after the first vegetation period. The plants with green needles were evaluated as surviving after the first vegetation period.

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The effect of STOCKOSORB® application on the survival and growth of spruce seedlings was also tested under practical conditions after transplanting. At the beginning of June the transplanting of two-year spruce seedlings (height 9.1 cm; diameter of root collar 2.2 mm) was carried out. The root system of seedlings was treated with STOCKOSORB® directly after lifting. The same preparation of gel was used as in the previous test. The transplanting was made with a transplanter on the same day as lifting. The transplanted seedlings were regularly irrigated two weeks after transplanting and then the irrigation was stopped. At the end of vegetation period the survival, height and root collar diameter were determined.

The values of electrolyte leakage from roots after desiccation tests, height and root collar increments were evaluated by Tukey's honest significant difference (HSD) test.

RESULTS

1. Assessment of desiccation effect on the physiological quality of spruce seedlings

Table 1 presents the values of electrolyte leakage from the root system after different times of desiccation. The rate of electrolyte leakage statistically increased with the duration of stress factor (34% for control seedlings and 53% after 5 hours of desiccation treatment).

Statistically significant differences were found in height and root collar diameter increments after the first vegeta-

Table 1. The rate of electrolyte leakage (%) and the level of significance after artificial desiccation stress

Treatment	REL(%) ± one standard error
Control	34 ± 3[a]
2 hours	38 ± 7[a/b]
4 hours	47 ± 10[b/c]
5 hours	53 ± 8[c]

For Table 1–5: Tukey's HSD test was used for means separation ± standard error of treatment at the 5% level. Different letters show significant differences

Table 2. Height and diameter increments after artificial desiccation stress

Treatment	Height increment (%)	Root collar diameter increment (%)
Control	45[a]	36[a]
2 hours	35[b]	26[b]
4 hours	28[b]	18[b]
5 hours	6[c]	8[c]

Table 3. The rate of electrolyte leakage (%) and the level of significance after artificial desiccation stress (STOCKOSORB treatment)

Treatment	REL(%) ± one standard error
Control	36 ± 5[a]
2 hours	43 ± 6[a/b]
4 hours	48 ± 8[b]
5 hours	48 ± 12[b]

Table 4. Height and diameter increments after artificial desiccation stress (STOCKOSORB treatment)

Treatment	Height increment (%)	Root collar diameter increment (%)
Control	47[a]	49[a]
2 hours	42[b]	48[a]
4 hours	32[c]	28[b]
5 hours	22[d]	14[c]

Table 5. Height and root collar diameter of spruce seedlings

Treatment	Height (cm)	Root collar diameter (mm)
Seedlings without STOCKOSORB	13.2[a]	2.3[a]
Seedlings with STOCKOSORB	18.3[b]	3.4[b]

tion period (Table 2). 100% survival was observed in the plants in all variants.

2. Assessment of STOCKOSORB® application for the protection of spruce seedling roots

Forest nursery of Forest Research Institute

Table 3 shows the values of electrolyte leakage from the root system of spruce seedlings treated with STOCKOSORB® after lifting. The electrolyte leakage increased with stress intensity; on the other hand, the rate of electrolyte leakage was smaller than in seedlings without hydrogels after 5 hours of desiccation stress. The height and root collar increments decreased with the duration of desiccation treatment but it was higher in all variants of seedlings treated with hydrogels (Table 4).

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In previous tests, the seedlings were exposed to controlled stress conditions. A test was realized under practical conditions in a forest nursery. Table 5 presents the values of height and root collar diameter of transplanted seedlings with STOCKOSORB®AGRO application after the first vegetation period. The height and root collar diameter were statistically different and the survival of plants was about 97% for seedlings with hydrogel application and 92% without hydrogel.

DISCUSSION

The amount of available water in the soil is crucial for the quality and efficiency of plant growth. The factor is very important for seedlings after transplanting. The root system is not protected with soil during this operation. Therefore, it increases the risk of desiccation injury of the root system. This risk is very high for fine roots. It is necessary to protect the root system during transplanting and to provide a sufficient amount of available water directly after transplanting. This water is crucial for the growth of new roots and nutrient and water uptake.

The planting stock of forest species has 50–86% water content in fresh condition (DIMPMEIER 1969). This high water content plays a decisive role for a successful survival of planting stock. The root system is very susceptible to desiccation injury (CHALUPA 1977).

In this study the influence of desiccation on the physiological quality of spruce seedlings was examined. Another goal was to determine a possibility of STOCKOSORB® application for root protection during transplanting.

1. Assessment of desiccation effect on the physiological quality of planting stock

In general, there are many studies that reported a possibility of measuring electrolyte leakage to determine physiological injury. This injury was caused by desiccation (FAN, BLAKE 1994; SARVAŠ 1998, 2002, etc). Some authors used these measurements: a) to determine lifting dates for barerooted seedlings (MCKAY 1992, 1993, 1994, 1998; MCKAY, MASON 1991; MCKAY, MORGAN 2001, etc.), b) to assess frost damage to trees and to determine the levels of frost hardiness (BIGRAS, COLOMBO 2001; COLOMBO 1994, 1997; ÖGREN 2001; NICOLL et al. 1996; SARVAŠ 2001, etc), and c) heat damage (BINDER, FIELDER 1995).

In this test the rate of electrolyte leakage increased statistically significantly with the duration of stress (34% for control seedlings and 53% for seedlings after 5 hours of desiccation treatment). The artificial desiccation significantly affected height and root collar diameter increments after the first vegetation period. SARVAŠ (2002) found a 36% rate of electrolyte leakage from unstressed seedlings. On the other hand, the same seedlings had a 47% rate of electrolyte leakage after artificial desiccation stress (6 h/16°C). In this study the height increment decreased from 49% (unstressed seedlings) to 2% (seedlings after 6 hours of desiccation).

In this study morphologically nearly the same seedlings were used as those by SARVAŠ (2002) (root collar diameter 3.1 and 3.2 mm, respectively). Therefore the rate of electrolyte leakage over 40% probably signals the physiological damage of spruce seedling root system. It is necessary to underline that these values of electrolyte leakage related to seedlings with the root collar diameter about 3 mm. SMIT-SPINKS et al. (1984) described that hardiness of suberized roots varied with root diameter, generally hardiness increases with increasing diameter. SARVAŠ (1999) found 23% electrolyte leakage from tap roots of unstressed spruce plants (root collar diameter 12.6 mm).

2.Assessment of STOCKOSOR® application for the protection of spruce seedling roots during transplanting

Forest nursery of Forest Research Institute

After lifting the seedlings were treated with hydrogel STOCKOSORB®. Next, the seedlings were placed under same conditions as in the previous artificial desiccation test and the electrolyte leakage was measured. The seedlings were transplanted and the height and root collar diameter increments were measured after the vegetation period.

The rate of electrolyte leakage from root systems with hydrogel was lower than from controlled seedlings after 5 hours of desiccation stress. On the other hand, the rate of electrolyte leakage two hours after desiccation treatment was higher in seedlings without STOCKOSORB application. Highly probably, the rate of electrolyte leakage was affected not only by the cell damage but also by the application of hydrogels. According to MCKAY (1992) root material for electrolyte leakage measurements is rinsed in deionized water to remove surface ions. Therefore, it is needful to use the sample without surface ions for electrolyte leakage measurements. On the other hand, the chemical composition of hydrogel could affect the rate of electrolyte leakage.

The seedlings (without stress factor) had 47% (with hydrogel) and 45% (without hydrogel) height increments. The seedlings without hydrogel showed 35% height and 26% root collar diameter increments, respectively, after two hours of desiccation stress. On the other hand, the same seedlings with STOCKOSORB had 42% height and 48% root collar increments.

In general, the application of hydrogel had positive effects on height and diameter increments. No mortality of seedlings was observed. But it is necessary to underline that the seedlings after desiccation treatment were transplanted to containers and placed to a nursery bed with regular irrigation and weed control. Therefore, these seedlings were under a smaller transplanting shock than the plants set out directly to cutting areas.

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The application of STOCKOSORB® for the protection of spruce seedling roots was tested in nursery practice. The results showed significant differences in biometrical characteristics after the first vegetation period. The seedlings with hydrogel application were on average 5 cm higher and had 1 mm larger root collar diameters than seedlings without hydrogel.

CONCLUSION

These results demonstrate a possibility of measuring electrolyte leakage from the root system to assess the physiological quality of seedlings. The rate of electrolyte leakage up to 40% signals a decrease in the physiological quality of spruce seedling root systems (root collar diameter about 3 mm).

The results point to the need of root protection against desiccation. The application of hydrogel for root protection during the handling of planting stock can decrease a transplanting shock. For root protection it is necessary to use hydrogels with smaller granules that can cover the whole root system and supply enough moisture to prevent dehydration of exposed roots. The application of hydrogel could also be used for a reforestation program. Highly probably, this use of hydrogel can protect the root system of planting stock against desiccation during handling, transporting and afforestation. Apart from the protection of the root system during transporting and handling this application could reduce a transplanting shock.

The hydrogel STOCKOSORB® has a particle size of 0.2–0.3 mm. It has been specially formulated for safe use in the production of food crops. The relatively larger size of granules and fine roots of seedlings caused that the gel sank from the root system. Therefore it would be better to use a hydrogel with small particular size.

It is needful to carry out further research on a new generation hydrogels in forest nursery and reforestation and afforestation programmes in the environmental conditions of Central Europe.

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Vplyv sucha na koreňový systém semenáčikov smreka (*Picea abies* [L.] Karst.) a možnosti aplikácie hydrogelu STOCKOSORB® na jeho ochranu

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ABSTRAKT: Cieľom štúdie bolo: 1. zistiť vplyv sucha na fyziologickú kvalitu semenáčikov smreka pomocou merania straty elektrolytu z koreňového systému; 2. testovanie použitia hydrogelu STOCKOSORB® na ochranu koreňového systému semenáčikov smreka počas škôlkovania. Na základe získaných výsledkov je možné konštatovať, že hodnoty straty elektrolytu stúpali s dĺžkou pôsobenia stresového faktora a tieto rozdiely boli štatisticky významné (34% hodnota straty elektrolytu pre kontrolné semenáčiky a 53% po piatich hodinách pôsobenia stresového faktora). Rovnako boli zaznamenané štatisticky významné rozdiely vo výškovom a hrúbkovom prírastku po prvej vegetačnej perióde, ktoré klesali s dĺžkou pôsobenia stresového faktora. Výsledky ukázali, že hodnoty straty elektrolytu stúpali s dĺžkou pôsobenia stresového faktora aj po ošetrení koreňového systému hydrogelom, ale na druhej strane tieto hodnoty boli nižšie po piatich hodinách pôsobenia sucha ako pri semenáčikoch, ktoré neboli ošetrené hydrogelom. Hodnoty výškového a hrúbkového prírastku boli pri všetkých variantoch vyššie ako pri semenáčikoch, ktoré neboli ošetrené hydrogelom. Získané výsledky štúdie demonštrujú možnosť použitia merania straty elektrolytu z koreňového systému na určenie fyziologickej kvality semenáčikov smreka. Hodnota straty elektrolytu na 40 % signalizuje fyziologické poškodenie koreňového systému semenáčikov smreka. Rovnako výsledky poukazujú na potrebu ochrany koreňového systému proti suchu počas manipulácie so semenáčikmi. Semenáčiky, ktoré neboli ošetrené hydrogelom, dosiahli 35% výškový a 26% hrúbkový prírastok po dvojhodinovom pôsobení stresového faktora. Na druhej strane semenáčiky, ktoré boli ošetrené hydrogelom STOCKOSORB, dosiahli 42% výškový a 48% hrúbkový prírastok.

Kľúčové slová: sucho; strata elektrolytu; hydrogel STOCKOSORB®; koreňový systém; smrekové semenáčiky

Základom úspešnej umelej obnovy lesa je dopestovanie kvalitného sadbového materiálu v lesnej škôlke. Morfologická kvalita je veľmi ovplyvňovaná rozdielnymi postupmi, ktoré sa používajú v lesnej škôlke a škôlkovanie patrí medzi operácie, ktorých cieľom je zlepšiť parametre koreňového systému sadbového materiálu. Počas tejto operácie vzniká veľké nebezpečenstvo poškodenia koreňového systému semenáčikov vplyvom pôsobenia vonkajšieho prostredia (slnečné žiarenie, vietor, teplota). Tieto faktory môžu zapríčiniť fyziologické poškodenie koreňového systému semenáčikov a tým zníženie ujatosti a následného rastu po zaškôlkovaní. Preto sa hľadajú nové metódy na zistenie tohto fyziologického poškodenia a rovnako aj postupy ochrany koreňového systému a tým zvýšenie ujatosti.

Cieľom štúdie bolo zistiť vplyv sucha na fyziologickúkvalitu semenáčikov smreka pomocou merania straty elektrolytu z koreňového systému a testovanie použitia hydrogelu STOCKOSORB® na ochranu koreňového systému semenáčikov smreka počas škôlkovania.

Zistenie vplyvu sucha na fyziologickú kvalitu smrekových semenáčikov

Trojročné semenáčiky smreka (výška nadzemnej časti 19,2 cm; priemer koreňového krčka 3,2 mm) boli 25. 3. 2002 vyzdvihnuté zo záhonu lesnej škôlky. Priamo po vyzdvihnutí boli semenáčiky vystavené suchu (semenáčiky boli jednotlivo umiestnené na betónovú cestu a vystavené po dobu 2,4 a 5 hodín pôsobeniu sucha – teplota vzduchu bola 17 °C, slnečno). Po ukončení pôsobenia stresového faktora sa uskutočnilo meranie straty elektrolytu z koreňového systému a rovnako z každého variantu bolo presadených do rozpojiteľných obalov po 10 semenáčikoch, na ktorých sa v jesennom období hodnotila ujatosť, výškový a hrúbkový prírastok. Na základe získaných výsledkov je možné konštatovať, že hodnoty straty elektrolytu stúpali s dĺžkou pôsobenia stresového faktora; tieto rozdiely boli štatisticky významné (34% hodnota straty elektrolytu pre kontrolné semenáčiky a 53% po piatich hodinách pôsobenia stresového faktora). Rovnako boli zaznamenané štatisticky významné rozdiely vo výškovom a hrúbkovom prírastku po prvej vegetačnej perióde, ktoré klesali s dĺžkou pôsobenia stresového faktora.

Hodnotenie vplyvu aplikácie hydrogelu STOCKOSORB® na ochranu koreňového systému semenáčikov smreka

Lesná škôlka na Lesníckom výskumnom ústave

Na testovanie boli použité semenáčiky z rovnakého záhonu v lesnej škôlke ako v predchádzajúcom pokuse. Koreňový systém semenáčikov po vyzdvihnutí bol ošetrený pripraveným gelom STOCKOSORB® a následne bol indukovaný rovnaký stresový faktor, meranie straty elektrolytu a presadenie do rozpojiteľných obalov ako v predchádzajúcom pokuse.

Výsledky ukázali, že hodnoty straty elektrolytu stúpali s dĺžkou pôsobenia stresového faktora, ale na druhej strane tieto hodnoty boli nižšie po piatich hodinách pôsobenia sucha ako pri semenáčikoch, ktoré neboli ošetrené hydrogelom. Rovnako aj hodnoty výškového a hrúbkového prírastku boli pri všetkých variantoch vyššie ako pri semenáčikoch, ktoré neboli ošetrené hydrogelom.

Lesný závod Beňuš, lesná škôlka Drakšiar

Vplyv aplikácia hydrogelu STOCKOSORB® bol hodnotený v škôlkárskej praxi. Začiatkom júna bolo uskutočnené škôlkovanie dvojročných semenáčikov smreka (výška nadzemnej časti 9,1 cm; priemer koreňového krčka 2,2 mm). Priamo po vyzdvihnutí bol koreňový systém semenáčikov namočený do pripraveného hydrogelu a následne zaškôlkovaný na školničnú plochu (+ kontrolné neošetrené jedince). Po prvej vegetačnej perióde sa zisťovala výška nadzemnej časti a priemer koreňového krčka. Boli zistené štatisticky významné rozdiely v prospech semenáčikov, ktoré boli ošetrené hydrogelom.

Výsledky tejto štúdie demonštrujú možnosť použitia merania straty elektrolytu z koreňového systému na určenie fyziologickej kvality semenáčikov smreka. Hodnoty straty elektrolytu nad 40% úroveň signalizujú pokles fyziologickej kvality koreňového systému semenáčikov (priemer koreňového krčka okolo 3 mm).

Rovnako výsledky poukazujú na potrebu ochrany koreňového systému proti suchu. Aplikácia hydrogelu na ochranu koreňového systému môže znížiť šok z presadenia. Je potrebné použiť pre tento účel hydrogel menšej frakcie, ktorý je schopný pokryť celý koreňový systém. Aplikáciu hydrogelov je možné použiť aj pri umelej obnove lesa. Táto aplikácia môže ochrániť koreňový systém sadbového materiálu proti vyschýnaniu počas manipulácie a transportu. Je potrebné uskutočniť výskum tejto aplikácie v prírodných podmienkach strednej Európy.

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