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ORIGINAL PAPER

Comparison of Norway spruce artificial regeneration techniques tested in the area destroyed by spruce bark beetle in Kysuce Region (Slovakia)

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Abstract

Ongoing coniferous monocultures decline in Beskydy Mts. Slovakia, emerged into establishment of Demonstration object of reconstruction of spruce forests (DORS) Husárik, focused on various technological processes of regeneration of economically important tree species. For Norway spruce (*Picea abies* [L.] Karst.) assessment of less frequently used artificial regeneration technologies, including planting of containerized transplants (CRT) or direct seeding procedures (direct seeding DS, seeding into vegetation cell VCS) and commonly used planting of bareroot transplants (BRT) was carried out. Seven years after experimental plot establishment, the lowest survival rate was recorded for DS treatment with 42% survived seedlings, the highest for CRT treatment with 79% survived transplants. For germinated seedlings, average seeding spot occupation rate recorded for DS (72%) was significantly lower than for VCS (98%) one year after seeding and remained significantly lower also over further consecutive years. Average survival recorded for planted transplants over monitored period did not differ markedly and gradually decreased to 76% for BRT and 79% for CRT. Reflecting different ontogenetic stage of individuals assigned to selected treatment average height 134.6 cm for DS, 134.1 cm for VCS and 182.0 cm for CRT, 215.0 cm for BRT was recorded seven years after establishment. The results suggest that for spruce, less frequently used artificial regeneration technologies (VCS, CRT), that markedly curtail time period required for target tree species installation on planting sites, with survival and growth rate of plants recorded in this study, could provide reasonable alternative to commonly used planting of BRT.

Key words: spruce decline; reconstruction; planting; seeding; containerized and bareroot transplants

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1. Introduction

Although, restoration of significantly disturbed coniferous monocultures situated in Central Europe put in advance planting of deciduous tree species or other conifers (Ammer & Kölling 2008; Konôpka et al. 2013; Vacek et al. 2019), planting of autochthonous Norway spruce (*Picea abies* [L.] Karst.) on sites with favourable conditions still remain a reasonable option for enhancement of high quality wood production of local forest stands (Vladovič et al. 2003; Kozak et al. 2013; Čermák et al. 2021). In 2020, Norway spruce, with more than 3.106 planted transplants, was the second most commonly planted tree species within forests managed by state enterprise Lesy SR, š. p., the largest owner of forests in Slovakia (Bruchánik 2020). Likewise to other tree species, an option related to minimizing time gap between the creation of site proposed for reforestation, and establishment of new tree species plantation, have a key impact also on successful establishment of Norway spruce plantations (Jobidon et al. 2003; Thiffault et al. 2013; Konôpka et al. 2021). In conditions of mountainous forests of Central Europe, every delay in establishment of targeted tree species on reforested sites contribute to rapid establishment of unwanted vegetation (weed, bushes, pioneer tree species), that has marked effect on effectiveness of engaged artificial regeneration practices as well as initial development of planted individuals of target tree species after planting (Konôpka et al. 2017; Repáč et al. 2021).

One of the most important assumption for successful regeneration of reforested area is availability of sufficient

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amount of high quality planting material that is usually produced in the forest nursery. However, recent large scale disruption of forests and subsequent unplanned increasing area of reforestation demanding sites (Konôpka & Konôpka 2007; Kunca et al. 2015; Zahradník & Zahradníková 2019), markedly deplete capacities of producers of forest reproductive material with limited material equipment and labour sources (Mlčoušek & Křístek 2021). Further complications emerged also from restrictions related to horizontal and vertical transfer of produced forest reproductive material (Repáč et al. 2017; Mlčoušek & Křístek 2021). Moreover, for Norway spruce, satisfaction of fluctuating demand for reproductive material is hampered also by the length of four-year period used for cultivation of the bareroot transplants, the most commonly planted Norway spruce stocktype in Slovakia (Repáč et al. 2017; Bruchánik 2020). However, four-year old bareroot seedlings of Norway spruce with high survival rates as well as sufficient growth after planting represent reliable technology of this tree species establishment under conditions of planting sites situated in Central Europe, (Leugner et al. 2009; Koňasová et al. 2011, Repáč & Belko 2020).

Development of technologies enabling acquirement of forest tree species planting material of desirable quality within reduced time period resulted for Norway spruce into conceptualization of new procedures and techniques that were capable to produce morphologically enough developed spruce transplants within one growing season (containerized seedlings) (Leugner et al. 2009; Landis et al. 2010; Zahradník et al. 2018). Besides shorter period required for cultivation of containerized compared to bareroot spruce transplants, containerized transplants have also other benefits including: lower risk of root system damage, lower susceptibility to growth check, better survival and growth after planting (Leugner et al. 2009; Grossnickle & El-Kassaby 2016). On the other hand, shortened cultivation cycle of planting material in container nurseries have also constrains related to lower flexibility of equipment demanding technology (greenhouses with regulated water and nutrient regime, storage places, cultivation trays etc.), that may fail to satisfy unexpected demands of large salvage felled areas (Landis et al. 2010; Mlčoušek & Křístek 2021).

Nevertheless, artificial establishment of target tree species on salvage or clear felled areas do not have to be necessarily realized through planting of nursery grown transplants (Palma et al. 2015; Grossnickle & Ivetić 2017). Experimental reforestation technologies including recruitment of individuals from seeds directly sown into the substrate or mineral soil of reforested site represent immediately available alternative to conventionally used planting of transplants (Erefur et al. 2008; Grossnickle & Ivetić 2017; Repáč et al. 2017). Currently, modification of standard direct seeding of seeds into the mineral soil, with placement of seed into plastic tube (vegetation cell) filled with substrate and installed in seeding hole is under investigation with promising preliminary results (Tučeková 2015). The technology of seeding into vegetation cells, developed and patented in Czech republic consists of following steps comprehensively described by Tučeková (2015): i) digging a hole with a depth of 10 cm and a diameter of the used cell (plastic tube) – that is, approximately 8 cm; ii) placement of 5 cm thick layer of sowing substrate on the bottom of the digged hole; iii) seeding the seed on a compacted layer of substrate; iv) placement of further layer of substrate or moistened perlite over seed; v) placement of cap on the open top of vegetative cell. If necessary, it is possible to protect the sowing of large seeds (deciduous trees) from rodents by applying wire covers adjusted to the top of plastic tube.

Extensive coniferous monocultures decline in Beskydy Mts. Slovakia, driven mainly by biotic agents-bark beetles (Scolytidae) and honey fungus (*Armillaria* sp.) that started after 2002 led to formation of large cleaned areas after sanitary cuttings (Tučeková & Longauerová 2008; Sitková & Šebeň 2012). In 2009 reforestation programs conducted on these sites emerged into establishment of Demonstration object of reconstruction of spruce forests (DORS) as a part of the project "Demonstration object of the conversion of dying spruce forests into ecologically more stable multifunctional ecosystems (Sitková & Šebeň 2012). Practical demonstration, verification and follow-up systematic research of various alternatives of forest regeneration on salvage felled clearings of DORS Husárik included also experimental assessment of various artificial regeneration practices.

The main aim of this study is to verify the ability of spruce less frequently used artificial regeneration technologies including planting of containerized transplants or advanced direct seeding procedures, to provide reasonable alternative with survival and growth of established plants corresponding to commonly used planting of bareroot transplants.

2. Material and methods

2.1. Study site

The experimental plot (Experiment C) is one of 10 experiments conducted within DORS Husárik, situated in Javorníky Mts. (49°24´47˝N, 18°46´10˝E), established on salvage felled area, after disruption of mature spruce stand by bark beetle outbreak (Fig. 1). The experimental plot with spruce plantations and seeding was established in spring 2011. No competing vegetation was present on the site at the time of planting, but various herbaceous (predominantly *Calamagrostis* sp.) and pioneer tree species (birch, rowan, willow) gradually became abundant the following years. Weed as well as individuals of pio-

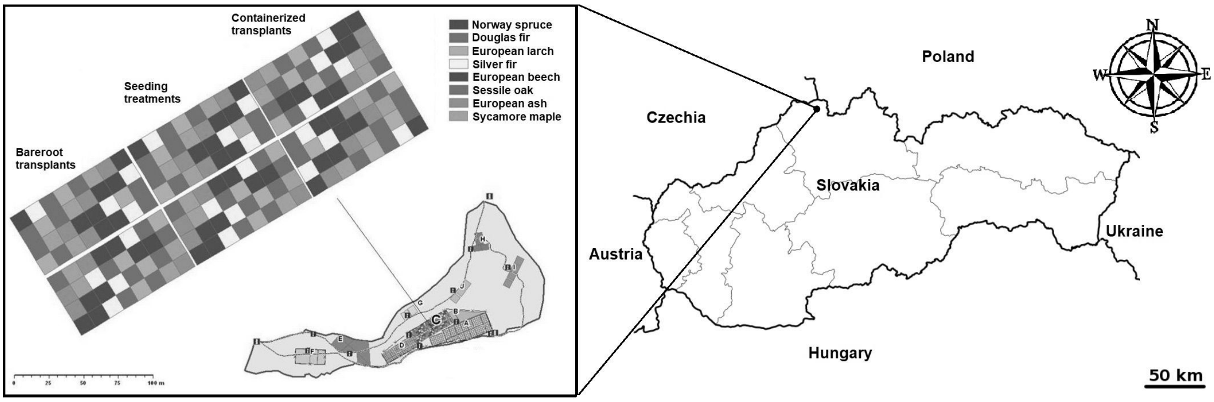

Fig. 1. Localization of experimental plot within Demonstration object of reconstruction of spruce forests (DORS) Husárik in Javorníky Mts. Slovakia (Adopted from Šebeň et al. 2011).

neer tree species grown within a 30 cm radius around the aboveground part of each spruce individual were removed manually with a grass-hook in July in each growing season. Individuals of pioneer tree species grown out of a 30 cm radius, were cut out by hand saw or axe every time they started to mechanically suppressed or reached 1.5–fold height of examined spruce individuals.

Mean altitude of the experimental plot is 770 m a. s. l., aspect NW and slope 30%. The soil of the experimental plot is silt loam (30% sand, 60% silt, 10% clay) cambisol with high content (>40%) of rock fragments (>2 mm) and acidic pH (pH_{H_2O} 4.9). The underlying bedrock comprises of sandstones (Čurlík & Ševčík 2012). The average length of growing season takes 170 days, long-term (1981–2010) mean annual air temperature at the study site reached 6–7 °C and mean annual precipitation 900–1,000 mm (Slovak Hydrometeorological Institute 2019).

2.2. Experimental design

The experimental plot was arranged in a randomized block design with 8 replications. For spruce, assessment of artificial regeneration techniques comprised of 4 treatments established in the spring 2011: i) direct seeding of seed into the mineral soil (DS); ii) seeding of seed into the vegetation cell (VCS); iii) planting of bareroot transplants (BRT); iv) planting of containerized transplants (CRT).

Seeding of seeds and planting of spruce transplants have been conducted on spots distributed in regular spacing 2 × 2 m on square subplots (12 × 12 m). For both seeding treatments 3–5 seeds were placed into the growth substrate, and then put directly into the mineral soil (DS) or into the plastic tube (vegetation cell) (VCS) installed on the seeding spot according to instructions described by Tučeková (2015). Planting of BRT and CRT spruce transplants was carried out manually into the holes of adequate size dug on spots 30 × 30 cm with hoe. In total, for BRT as well as CRT treatment 288 spruce transplants have been planted. For seeding treatments 2,400 seeds within 288 seeding spots established within DS as well as VCS treatment have been seeded. After planting, the area was treated according the common practice, including manual weed control and application of chemical repellents against game browsing to the leading bud and shoot as well as lateral buds and shoots at the first node of each spruce individual after each growing season.

2.3. Experimental material

Spruce seeds, used in this study for cultivation of transplants within planting treatments as well as within seeding treatments were collected in the same certified source of forest reproductive material in corresponding provenance region in 2006 (Registration code: pab01524NO–485; Seed zone: 2 Kysucko-oravská). Collected seeds were stored in sealed containers at low temperature (–3 °C).

The cultivation of spruce BRT started in the spring 2007. BRT were grown in the open nursery bed composed from the mixture (1 : 1, v : v) of soil and pure highly humified peat enriched with macronutrients. The substrate mixture was fumigated and the granule fertiliser NPK Cererit (Forestina Ltd., Mnichov, Czech Republic) was thoroughly mixed with approximately 10 cm upper layer of the substrate before seed sowing. After the beginning of the leading shoots growth, BRT were fertilised once weekly for the next 5 weeks. One–year–old BRT were overwintered on the seedbed and cultivated further year. In the beginning of the third growing season, spruce BRT were replanted to a soil bed and fertilised three times from a half of June on a 2-week interval. The seedlings were not fertilised in the fourth growing season. The BRT were irrigated and weeded manually or with herbicides if needed (Table 1).

The cultivation of spruce CRT started in the spring 2010. The CRT were cultivated in Quick Pot 35T plastic trays (BCC, Iso-Vimma, Finland, 35 cells per tray,

Table 1. Spruce seed and transplants (BRT – bareroot, CRT – containerized) characteristics used for experimental plantation establishment on experimental plot within DORS Husárik in Javorníky Mts.

Seeds	Germination	Germination energy	Mean germination time
	80%	25%	9 days
Transplants	Age	Stem height / Root collar diameter	
	BRT 2 + 2[1]	38.9 cm / 5.6 mm	
	CRT fk 1 + 0[2]	18.2 cm / 2.4 mm	

Notes: [1]transplants cultivated in mineral soil of seedbed for two years and then replanted again into seedbed and cultivated further two years; [2]transplants cultivated one growing season in plastic trays filled with growing substrate under greenhouse conditions.

350 cells m^{-2}, cell volume 200 cm^3) filled with peat-based growth substrate for two months in a greenhouse and subsequently in an open field in the forest nursery. The CRT were grown in the substrate (VermiVital Ltd., Záhorce, Slovakia) of following composition: white peat (0–20 mm) 80%, black peat (0–10 mm) 20%, powdered compound fertiliser PG Mix–macro – and micro–elements set (Yara International, Oslo, Norway) 1.9 kg m^{-3}, wetting agent Fibazorb (Turftech International Ltd, Preston United Kingdom) 0.1 l m^{-3}, stimulator of root growth Bioroot 200 ml m^{-3} (Desarrollos Agroquímicos S. A., Lleida, Spain). CRT were cultivated in the greenhouse without regulation of temperature, air humidity, and light regimes, which were affected by outdoor environmental conditions. Four weeks after the beginning of seedling emergence the CRT were fertilised twice weekly for the first three and the next 8 weeks, respectively. The polyethylene sheath of the greenhouse was removed 8 weeks after seedling emergence (Table 1).

In January 2011, sample of 400 seeds used within seeding treatments (DS, VCS) were draw back from storage, and seed quality parameters, were examined. Average seed germination rate across assessed samples reached 80%, germination energy 25% and mean germination time 9 days (Table 1).

2.4. Assessment of experimental material and statistics

The results presented in this study summarize seven consecutive years of experimental plot assessment after its establishment. For seeding treatments seeding spot occupation rate was estimated as the number of spots occupied by at least one vital germinated seedling from the total number of established spots in the first growing season and survival rate as the number of seeding spots with vital seedling, from the total number of established spots in further consecutive years. Survival rate for transplants (BRT, CRT) was estimated as the number of vital transplants from the total number of planted transplants separately for BRT and CRT. Assessment of morphological parameters over seven consecutive years of experimental plantation investigation was carried out only on undamaged individuals and included: stem height (H) and height increment (Hi), root collar diameter (RCD) and root collar diameter increment (RCDi). Hi was estimated as a length of terminal shoot produced by assessed individual, RCDi was estimated as a difference between RCD of assessed individual recorded over consecutive years. The number of damaged individuals did not exceed 10% of those that survived regardless of assessed treatment. Significance of differences among treatment means for seeding spot occupation rate, survival, Hi and RCDi were examined by Two-sample t test for difference of means separately for seeding treatments and for planting treatments. Statistical analysis was performed using STATISTICA 12.

3. Results

3.1. Seeding spot occupation rate and survival

Seven years after experimental plot establishment, the lowest survival rate was recorded for DS treatment with 42% survived seedlings, the highest for CRT treatment with 79% survived transplants. One year after experimental plot establishment average seeding spot occupation rate recorded for DS (72%) was significantly lower than for VCS (98%) (Fig. 2; $p < 0.05$). For germinated seedlings occupying seeding spots, gradual decrease of survival over further consecutive years has been observed. Seven years after seeding, average survival of germinated seedlings was 42% for DS and 68% for VCS. For planted transplants, slightly higher survival for CRT (97%) than for BRT (86%), was observed only in the first year after planting. Seven years after planting, average survival recorded for BRT was 76% and for CRT was 79% (Fig. 2).

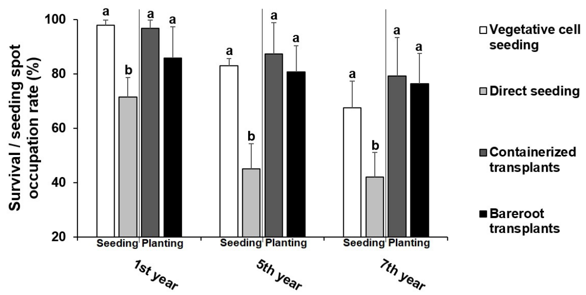

Fig. 2. Seeding spot occupation rate and survival (mean; standard deviation) of germinated seedlings and planted transplants of spruce recorded after 1st, 5th and 7th year after establishment of experimental plot of DORS Husárik in Javorníky Mts. Treatment means followed by the same letter are not significantly different (t-test; $p < 0.05$).

3.2. Growth of germinated seedlings and planted transplants

Seven years after experimental plot establishment average H 134.6 cm for DS, 134.1 cm for VCS and 182.0 cm for CRT, 215.0 cm for BRT was recorded (Table 2). One and two years after experimental plot establishment, Hi recorded for DS (12.5 cm) did not markedly differ from Hi of VCS (15.0 cm). In third and fourth year, VCS produced significantly lower Hi than DS (Fig. 3; $p < 0.05$). Five and seven years after seedling establishment, differences recorded for Hi between VCS and DS were not statistically significant. For planted transplants, CRT and BRT reached similar average Hi one year after planting. Two years after planting CRT produced significantly ($p < 0.05$) larger Hi than BRT. Differences in Hi recorded over further three consecutive years between BRT and CRT were not statistically significant. Seven years after planting BRT produced significantly larger Hi than CRT (Fig. 3; $p < 0.05$).

Table 2. Average (± standard deviation) stem height and root collar diameter of germinated seedlings (VCS – vegetative cell, DS – direct seeding) and planted transplants (CRT – containerized transplants, BRT – bareroot transplants) of spruce recorded after 1st, 5th and 7th year after establishment of experimental plot of DORS Husárik in Javorníky Mts.

Treatment	Stem height [cm]			Root collar diameter [mm]		
	1st year	5th year	7th year	1st year	5th year	7th year
VCS	15.0 ±3.4	85.9 ±18.6	134.1 ±25.1	2.0 ±0.3	12.8 ±2.5	21.4 ±5.4
DS	12.5 ±3.1	107.8 ±20.6	134.6 ±18.7	1.9 ±0.2	13.5 ±3.0	18.5 ±4.4
CRT	23.3 ±5.2	155.0 ±25.7	182.8 ±26.5	3.9 ±1.0	29.0 ±4.5	35.6 ±5.1
BRT	44.4 ±8.7	195.0 ±30.1	215.0 ±31.7	7.4 ±2.5	38.0 ±5.6	48.9 ±6.2

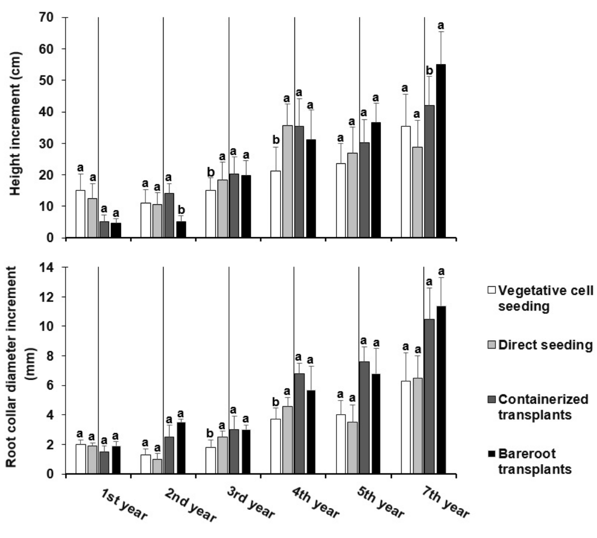

Fig. 3. Height increment and root collar diameter increment of germinated seedlings and planted transplants of spruce recorded over seven consecutive years after establishment of experimental plot of DORS Husárik in Javorníky Mts. Treatment means followed by the same letter are not significantly different (t-test; $p < 0.05$).

One year after plantation establishment, average RCD recorded for seedlings was 1.9 mm for DS, 2.0 mm for VCS and for transplants 7.4 mm for BRT and 3.9 mm for CRT. Over seven consecutive years of plantation assessment RCD increased for DS to 18.5 mm, VCS to 21.4 mm, BRT to 48.9 mm and CRT to 35.6 mm (Table 2). For planted transplants, recorded values of RCDi for BRT and CRT reached similar values in each of the consecutive year. Except of temporal decrease of RCDi recorded for VCS compared to DS in the third and fourth year after planting, any significant difference in RCDi has not been detected between seeding treatments (Fig. 3).

4. Discussion

In this study, average survival of the spruce reference BRT was 76%, H 215 cm and RDC 48.9 mm, seven years after planting. Recorded survival rate as well as growth observed for BRT, over an extended period after planting, did not markedly differ from survival rates of spruce planting material reported in other studies conducted in Slovakia (Repáč 2019; Repáč & Belko 2020; Repáč et al. 2021) or Czech Republic (Koňasová et al. 2012; Kuneš et al. 2013; Mauer et al. 2018). However, significantly lower values of Hi recorded for BRT two years after planting as well as slightly lower survival rates compared to CRT one year after planting suggest on better early adaptation ability of CRT on planting site conditions in this study. In spite of prevailing size gap between commercially produced spruce CRT and BRT transplants (Leugner et al. 2009; Jäärats et al. 2016; Repáč et al. 2017), growth increment or initial survival of CRT corresponding or slightly outperforming BRT during early years after planting have been observed also by Repáč & Belko (2020), Renou-Wilson et al. (2008), Klavina et al. (2013) or Jäärats et al. (2016). According to Grossnickle & El-Kassaby (2016) better ability of CRT compared to BRT to overcome transplant shock under field conditions is related to crucial feature of CRT seedlings, well developed root system concentrated within the root plug. Root plug of CRT seedlings protect root system before damage, provide favourable conditions for growth of new roots, as well as residues of water and mineral nutrients from nursery cultivation period, that are further available for transplants also under field conditions (Idris et al. 2004; Leugner et al. 2009; Grossnickle & El-Kassaby 2016). However, once a larger and more developed spruce BRT overcome planting check and become established, larger biomass of assimilatory organs, roots and other structures enable BRT transplant to accumulate more supplies required for growth and then produce also larger biomass increment (Hytönen & Jylhä 2008; Grossnickle & El-Kassaby 2016). In our study, significantly larger Hi of BRT than CRT have been recorded already after the fifth year after planting.

In this study, placement of seed into the substrate regardless of seeding treatment (VCS, DS) had probably stimulating effect on germination as well as initial establishment success of germinated seedlings. First year seeding spot occupation rate reaching 72% for DS and 98% for VCS markedly outperform findings of Erefur et al. (2008) and Fløistad et al. (2018) with less than 40% germinated spruce seeds seeded directly into the mineral soil. Furthermore, germinated seedlings have showed also high initial adaptation ability to field condition reaching stem height and root collar diameter of nursery grown spruce seedlings of corresponding age (Slávik 2005; Vaario et al. 2009). Even though, small dimensions of germinated seedlings have markedly handicapped spruce juveniles during early growth stages. During initial years after planting, lower dimensions of germinated seedlings hamper identification of artificially established individuals of target tree species that may be often overgrown by surrounding vegetation and thus increase the time consumption required for post-planting care interventions (weeding, protection against game) (Erefur 2008; Grossnickle & Ivetić 2017; Fløistad et al. 2018).

According to our observation, distinctively harmful impact of competing vegetation on germinated spruce seedlings persisted during early two years after planting. Weed mechanically push on the seedlings, capture growing space and reduce available light, water and nutrient (Grossnickle 2000). Additionally, size gap among germinated seedlings and planted transplants with average H of BRT and CRT exceeding 180 cm suggest that plantation established by planting of transplants have already had all mandatory features and can be classified as secured culture without further post-planting care interventions. On the other hand, plantations established by seeding treatments still require for VSC treatment further weed control, and for DS treatment also further plantation improvement with new individuals.

However, forest artificial regeneration procedures based on planting of tree species transplants on planting sites, including manipulation with living organisms, are always connected with the high risk of planting material physiological status deterioration (Grossnickle 2012). Further complications and perils arise also from possibility of improper installation of root systems of transplants into the soil, that may hamper root system development and its functions in the future (Grossnickle 2005). On the other hand, development of organism structures, especially root system, in more nature-like patterns already observed for seedlings of selected forest tree species (e.g.: *Pinus* sp., *Quercus* sp., *Pseudotsuga menziesii*, etc.) raised from seed (Grossnickle & Ivetić 2017), bring reasonable benefits, making reforestation techniques based on direct seeding of seeds on reforested sites under certain conditions more appreciated (Palma & Laurance 2015; Grossnickle & Ivetić 2017).

5. Conclusions

Assessment of experimental plot focused on comparison of spruce artificial regeneration techniques within DORS Husárik in Javorníky Mts. over seven consecutive years after establishment suggest that less frequently used artificial regeneration techniques, including planting of CRT or advanced direct seeding procedures could provide applicable alternative with survival and growth rate of established individuals conformable with commonly used BRT. The most remarkable finding of this study has been successful establishment of spruce seedlings within VCS. Seven years after experimental plot establishment VCS reached average survival 68%, height 134 cm and root collar diameter 21.4 mm. However, study observations related to VCS suggest also on limited application of this artificial regeneration practice. Especially, lower dimensions of germinated seedlings compared to planted transplants, put marked attention on precise and more frequent weed control, that should be carried out over a higher number of vegetation periods after planting. Further experimental plantation assessment over an extended time period as well as establishment of new experimental plots is needed to specify more precisely suitability of assessed artificial regeneration techniques also for other environmental conditions or tree species.

Acknowledgements

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