Reforestation in Slovakia: History, current practice and perspectives

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Abstract

The history of reforestation in Slovakia is long and rich; from reforestation by seeding, through the small forest nurseries, reforestation of extreme degraded and high-mountain sites to the current The Act on forest reproductive material, nursery centers and reforestation of large windthrow areas. After brief introduction of the history, rather large part of this review is dedicated to the current nursery and especially reforestation practices – planning, pre-planting site preparation, seeding and planting techniques, post-planting care, monitoring of planting performance. Recent nursery and planting research activities are given very shortly. Perspective nursery (e.g. improvement of seedlings' quality by inoculation with beneficial microorganisms, vegetative propagation) and reforestation treatments and practices (e.g. the use of larger amount of container-grown seedlings, application of hydrogels and ectomycorrhizal fungi, progressive seeding technique, underplanting) are relatively in detail but of course not comprehensively discussed finally. Despite of the lack of a complex reforestation strategy and current and possibly future financial sources and personnel limitations, the introduced perspective practices should contribute to successful solution of reforestation challenges following from endangering the forests by climate change.

Keywords

Reforestation; Planting; Nursery practices; Seedling quality; Seedling field performance; History; Slovakia

Contents

1 Introduction

Forests regeneration is an essential element of sustainable forest management. View on the forest regeneration has dramatically changed and evolved during recent periods depending on various external factors. Development and application of restoration methods were closely linked to ecological, economic and social conditions.

...“landscape of forests and wild bees“ (Herodotus, 5th century).

In the past, almost the whole territory of Slovakia was covered by forests. Human activities gradually changed the appearance of the landscape and forest cover had been significantly reduced. In recent years the area of forest cover had continually increased and in 2015 reached 2289,731 ha what represented 44.3% of the landscape. A relatively high proportion of forests is created by indigenous ecosystems (about 70%). On the one side, it is a result of a suitable forest management; on the other side, it places high requirements on the use of specifically adapted forestry interventions. Varied climatic and geomorphological conditions determine the diversity of forest communities. The surface of Slovakia is mostly mountainous and belongs to the Tertiary Carpathian Network (Fig. 1). Altitudes border from 94 m a.s.l. in lowlands in the south of Slovakia to the highest peak 2,654 m a.s.l. in the north (Gerlachovský štít). The climate is temperate, transitional between continental and oceanic, strongly influenced by altitude (warm, moderately warm and cold mountain climate). Average annual temperatures are approximately from 9°C in lowlands to -3°C on mountain tops. Annual precipitation totals vary from 500 mm (lowlands) to 2,130 mm (mountains).

Across the Slovakia, eight forest vegetation zones (from oaks to dwarf pine) are accompanied by a zonal forest ecosystems conditioned by climate, ground water table, soil and geomorphology. Slovak forests have a rather diverse tree species composition. The most abundant tree species include European beech (33.2%), Norway spruce (23.4%), and English and sessile oaks (10.6%). The broadleaved species prevail and comprise 62.2% of Slovak forests. The percentage of conifers has steadily decreased which is most apparent in the case of spruce, the presence of which, due to harmful agents, has declined by 2.9% in last 10 years (MPSR 2016). The growing stock in Slovak forests is gradually increasing as indicated by trends and actual age structure of forests. In 2015, the growing stock reached 478.12 million m^3 of timber inside the bark. The average stock was 247 m^3 of timber inside the bark per ha.

The fact, that Slovakia is among the top European countries due to the high forest cover, built forestry research and practice into the important position…

Slovakia lies in the heart of Europe, in the center of forestry events in the past but at present as well (Fig. 1). In 1770, lectures from forestry were the first time in history assigned to teaching at the Mining Academy in Banská Štiavnica, where also Forest Institute was created in 1807. The basics of forestry formulated here became the starting point for the forestry of the Austro-Hungarian Empire and also for the Europe at that time. The tradition of education and science has continued to these days. Society of Slovakia overcame a complicated development from the part of the Austro-Hungarian Empire (till 1918), through Czechoslovak Republic (1918−1938), Slovak republic (1939−1945) the Czechoslovak Socialist Republic (1960–1990), Czech and Slovak Federative Republic (1990−1992) to the present-day Slovak Republic (since 1993). This was connected with changes in management philosophy of the state and in laws what had also a significant impact on the development of forestry. The political changes changed also the proportion of forests in state and private ownership. In 1920 the state owned 20% of forests. With the advent of socialism, the share of state-owned forests increased; in 1950 almost 60% and in 1990 already around 92% of the forests belonged to the state ownership. After the restitution, Forests of the Slovak Republic (state enterprise) owns 43% and works on 55.5% of the forest. Although in these turbulent times the intensity of interest of the state and the public about forestry issues strongly varied, responsible approach to forests fortunately remained. Slovakia has significant sources of biodiversity and the proportion of forest areas included in the Natura 2000 is 46.5% (APA 2015). Today the issue of forest sustainability gets to the fore with the renewed urgency. The recent problems with emission load updated with the more and more pronounced climate change put new challenges for forestry. Also, methods and procedures for reforestation are subjected to many changes and innovations.

Figure 1. Geographic position of the Slovak Republic in Europe and its satellite map.

2 History

In ancient times and the early middle ages abundance of forests in our area forced people to gain their living space by slash and burn practices. In those times the principle "the forest grows by itself" was applied and regeneration took place only in the natural way. Grazing, production of timber, firewood, charcoal etc. strongly influenced our country. The human impact had led to large-scale forest clearance. Advancing deforestation mainly in population centers began to cause a local shortage of wood. The oldest methods of restoration were vegetative regeneration (coppice forest) and seeding of forest trees seeds. Regeneration of coppice forest became more widely applied in the 5th to 7th centuries and maintained a dominant position over the next few centuries. The existence of the coppice forest mostly in the southern and eastern Slovakia was shown by more contemporary written records and lot of them remained up to now. The concentration of harvesting operations, deforestation of large areas due to mining activities, grazing of livestock or agroforestry led to uncontrolled exploitation of timber and degradation of forest areas. Extreme lack of timber in place of processing threatened mining business, what was the major source of royal revenue. Emperors gradually began to solve this situation and enacted forestry orders and lows in order to rationalize the use of the forest. The forest order of Maximilian II (Constitutio Maximiliana 1565) was the first royal action against the destruction of forests and can be considered as the year of the more serious forest management beginning in our territory.

2.1 Seed management

The human activities mentioned above completely disabled natural regeneration and reforestation by seeding became the main solution. Stands coming from seeding were mentioned in written sources since the mid-13th century (Kavuljak 1942). Seeding of large deforested areas required a lot of seeds. Acute shortage of seeds conditioned the creation of seed companies, which due to increased profits and ignorance of the seeds genetic value traded with seed material of various countries and various qualities. In several countries, this resulted to distortions of forest tree authenticity (Kantor et al. 1975). Poor-quality and instability of non-indigenous stands encouraged the development of forest seed management. Development of seed management has been directed to its biologization. Seeds were examined for their morphology, physiology but also for their heritage value. In 1923, Forest Enterprise called Semenoles (Seed-Forest) focused on seed processing was founded and almost subsequently purchased by Government Forests, state enterprise, what had a decisive influence on the development of forest seed management in Slovakia. The main activities of this enterprise were in addition to seed management also protection of genetic resources and nursery production.

2.2 Nursery management

With the increasing importance of seed origin, effort to more rational and effective use of seeds steadily increased. Continually more extensive utilization of seeds for seedling production resulted in a consecutive decline of field seeding. The first official record of seedlings use dated back to mid-7th century. A significant milestone was the forestry regulation in the Codex Theresianus issued by Maria Theresa in 1769 for Hungarian Empire. It aimed to ensure the sustainability of production in forests and encouraged afforestation of unused areas. A true pioneer in this sphere was forester Jozef Dekrét Matejovie (1774−1841). In early 19th century, he extensively used reforestation by seedlings grown in him based nurseries. In the period 1809–1837 he reforested 3,910 ha of clear-cut areas by both seeding and outplanting of 1527,000 seedlings of spruce and larch (Vencurik 2016). He and many other important personalities in forestry initialized the development of nursery management in Slovakia. Since mid-19th century, much attention was devoted to nurseries. Many small nurseries were founded near outplanting areas and used the seeds of autochthonous tree species. Such planting of seedlings had many advantages and nurseries were a true gem of local foresters.

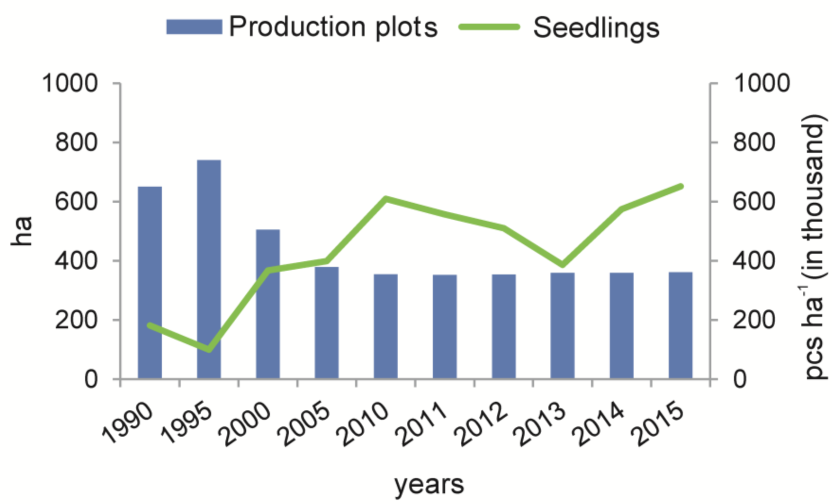

Figure 2. Production plots and an average number of seedlings grown per ha of the production plots in 1990–2015.

Constantly increasing demand for seedlings necessitated new approaches and solutions. Foundation of state-owned central nurseries in the 1980s allowed the introduction of mechanization, automation and new technological procedures. Although it was a controversial step in some views, economic advantages of these solutions were undisputed. An example of new technologies was vegetative propagation of Norway spruce. In the 1980s and 1990s, spruce stem cuttings were collected from resistance populations of north Slovakia regions damaged by air pollutants and rooted cuttings were in relatively large range outplanted back to these regions (Chlepko et al. 1991). In 2005 nursery production was concentrated into 13 central nurseries incorporated under forest enterprise Semenoles. This situation caused the disappearance of many smaller nurseries and reducing of nursery acreage (Fig. 2). The area of the nurseries (527 ha) and their production plots (361 ha) remains largely unchanged since 2005. An increase was reported in the production of planting stock, the volume of which totaled 235.4 million pieces in 2015. Production and handling of forest reproductive material (FRM) are strictly inspected by National Forest Centre.

2.3 Reforestation

From the period of laws of Maria Theresa, outplanting is linked to the clearings balance. The balance of the clearings was a key indicator for recording the quantity of silvicultural operations which were provided in The Act No. 100/1977 on forest management. Post-planting care and protection of young plantations issues were solved for a long time. The first mentions about hoeing were from the 18th century. In 19th and 20th-century weed control by manually multiple hoeing was a standard. To date, it failed to adequately replace manual work by mechanization. After the World War II, chemical herbicides become widespread due to their efficiency and cost saving. Their adverse ecological effects outweigh these benefits and contribute to the progressive decline of their use.

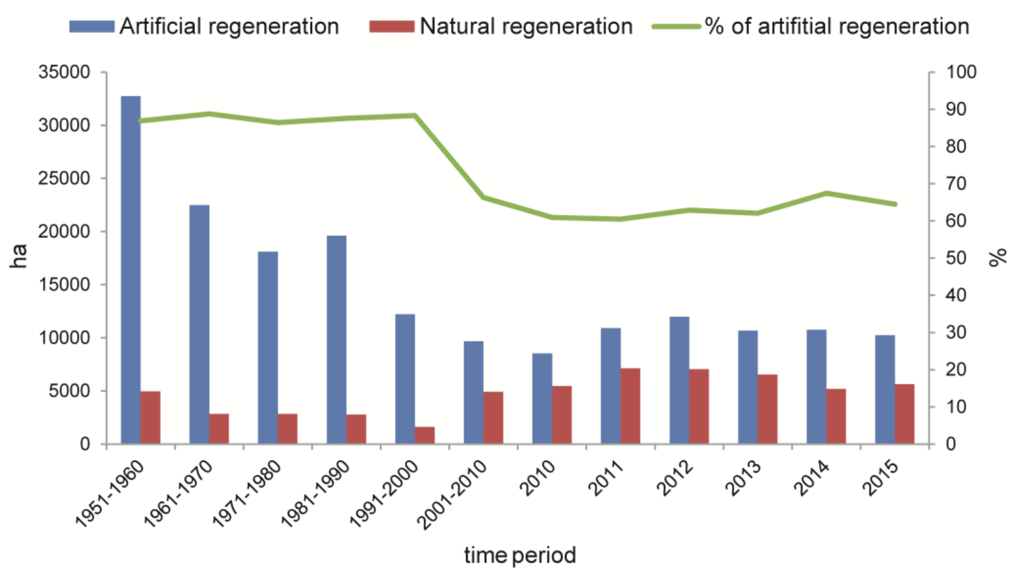

Figure 3. Forest restoration in Slovakia in the last 65 years.

Restoration of forest areas can be performed by natural regeneration or reforestation. Until 1990 about 20,000 ha annually was reforested and natural regeneration amounted only 11% of restored area (Fig. 3). The share of natural regeneration was strongly growing and in last 15 years reached 32.5–39.5%. It was caused by more factors but mainly by economic. Reforestation belongs to the most expensive items in forestry. It was, therefore, necessary to maximally exploit the reproductive potential of local genetically suitable forest stands. Natural regeneration is therefore not only saving tool but also a tool for the maintenance of a suitable gene pool (Sarvaš et al. 2007). The remaining ±65% was attributed to reforestation (MPSR 2016). The share of incidental felling on the total felling was relatively high, year on year to 42−65% and due to advancing climatic changes even higher values are expected. Extensive clearings, the need for changes in tree species composition, the need to increase forest cover, conversion from coppice to generative stands, or various limitations of natural regeneration would likely cause, that from the long-term view artificial regeneration probably doesn't drop below 8,000 ha.

2.4 Afforestation/reforestation important events

Afforestation of degraded localities

The period after World War II was dominated by efforts to reforest all of the abandoned strongly degraded localities and the Forestry Research Institute started research addressed to reforestation of mentioned extreme habitats. The most extreme localities, Periská and Slovak Karst, were on carbonate bedrock with shallow drying soil profile and with extreme fluctuations of temperature and humidity (Zachar et al. 1969, 1973). Their reforestation was a great challenge. The acquired knowledge served to improve reforestation techniques and the overall development of reforestation.

Reforestation in the High Tatra Mts.

The south side of the High Tatra Mts. has been regularly attacked by fierce wind. Extensive, progressively expanding windbreaks are here a common phenomenon. Forests mainly comprised of even-age spruce stands are extremely vulnerable in such conditions. Already in the 1950s the foresters were aware of the need for changes in tree species composition and structure of local stands. Great reforestation actions in 1953−1962 used both reforestation and natural regeneration. The forward-looking plan was aimed to increase the share of fir, pine, and larch, from broadleaved species beech and maple. Rowan, alder, and birch were accepted for reforestation of hardly reforestable areas. In 1987 the forest composition was as follows: spruce 41%, fir 15%, pine 11%, larch 11%, alder 9%, maple 6%, beech 3%, birch 0.2%, etc. In 1995 share of spruce further decreased to 35% (Jurčo 1995). Despite all efforts, extensive windbreak (4,505 ha) was repeated in 2004 (Fig. 4) and systemic treatments become necessary. The project for revitalization of forest ecosystems in the High Tatras had been created. The aim of forest regeneration was to create ecologically stable ecosystems close to nature structure with more diverse species, age and space composition than before wind event. Key principles which were applied in revitalization:

− The long duration of recovery of damaged stands.

− The application of small-scale forms of reforestation with emphasis on habitat and genetic suitability of plantations.

− The maximum use of natural regeneration and successional processes.

− Support for a small-scale mosaic of different development phases with significant vertical and horizontal diversity.

− Operational management practices based on long-term monitoring of environmental characteristics and conditions of forest ecosystems.

Figure 4. Windthrow and subsequent fire area in High Tatra Mts., north Slovakia.

Air polluted forests

Atmospheric acidification became a serious issue in large parts of Europe in the 1970s. Levels of atmospheric pollution in parts of central Europe were among the highest on the continent (Rydval and Wilson 2012). This was strongly reflected in the health status of Slovak forests; especially mountain spruce forest and fir were highly endangered. Due to pessimistic prognoses, a number of silvicultural methods have been developed to reduce the impact of air pollution. Reforestation in zones of emission load was associated with the requirement of minimizing losses by creating favorable conditions for development and growing of seedlings and with reducing seasonality of reforestation work (Grék et al. 1991). After the peak in 1980s, the amount of air pollution in the atmosphere had declined, what resulted to the overall revitalization of the ecosystems. This was reflected in the recent increase in fir and spruce growth (Bošeľa et al. 2013; Parobeková et al. 2016).

Afforestation of non-forest land

Based on the Concept of agricultural policy, the government of the Slovak Republic approved “Complex program of exploitation of soil production potential” for years 1994−1996 with a view to 2000. Ministry of Agriculture proposed to allocate for the afforestation 44−55,000 ha of non-forest lands which were unsuitable for agricultural production or due to the public interest in greening of the landscape. Afforestation improved the overall production potential of the soil and its ecological stability.

Revitalization of forests damaged by anthropogenic activities

Revitalization treatments in forests damaged by anthropogenic activities, especially by air pollutants, were oriented to the gradual recovery of forests and habitats, and to return their full functionality in the period 1996−2000. Depending on the extent and nature of the damage, the revitalization treatments in forests were divided into preventive and corrective (Table 1). Cover of the extra costs for the implementation of corrective treatments was funded from the state funds.

Table 1. The examples of forest revitalization treatments in Slovakia in the period 1996−2000.

Common treatment	Preventive treatment	Corrective treatment
Planting spot 25×25	Planting spot 35×35 with deeper soil loosening	Planting spot 60×60 with deeper soil loosening and fertilization
Standard number of seedlings	Increased number of seedlings	Increased number and quality of seedlings
Seedlings of standard quality	Seedlings of higher standard	Container-grown seedlings
-	-	Use of nurse tree species

2.5 The Rural Development Programs

The most important source of funds for the realization of the goals and treatments affecting the forestry of the Slovak republic was/is support from the European Union funds, mainly from the European Agricultural Fund for Rural Development (EARRD). Plans and Programs of rural development have been drawn up for periods 2004−2006, 2007−2013 and 2014−2020. The global goals of these programs were to increase the competitiveness of agriculture, food, and forestry, improve the environment by introducing of appropriate agricultural and forestry practices and improve the quality of life in rural areas with an emphasis on sustainable development. The main emphasis in forestry area was given in support of the environment, increasing the economic value of forests, education and land consolidation.

The Rural Development Plan 2004−2006 was oriented mainly on first afforestation of agricultural land with the main objective to strengthen the ecological stability of the country. The funds contributed to the eligible costs for:

− Manual or mechanized establishment of forest stands including the repeated planting after the first afforestation.

− Providing an annual payment per hectare of afforested areas within five years from the first afforestation to cover the costs of care for plantations.

The Rural Development Program 2007−2013 was oriented on restoring of forestry potential and introducing of prevention actions, and on first afforestation of agricultural land. The funds contributed to the eligible costs for:

− Implementation of corrective treatments in forests damaged by biotic and abiotic natural or anthropogenic stress factors.

− Establishment of forests, protection, post-planting care and tending of forests in forests damaged by biotic, abiotic and anthropogenic disturbances.

− Afforestation of the utilized agricultural land (hay meadows, pastures, arable land).

3 Current practices

3.1 Forest reproductive material

Now, only certified FRM originating or grown from certified sources can be used for reforestation. These certified sources include *selected trees* (trees of phenotype highest quality used for breeding and establishment of seed orchards), *certified forest stands* (selected mature stands of the highest phenotype quality), *clones* (vegetative progeny of selected trees), *seed orchards* (plantations of vegetative or generative progeny of selected trees). Upon meeting specific criteria and age, *seed stands* (stands arising from the renewal of certified forest stands) can also be included. Certified forest stands are the most common registered source of FRM. To protect the gene pool of forest tree species in Slovakia, 115 *gene bases* (forests with a special management regime) occupying area 19,829 ha are currently listed (Table 2). The great challenge for forestry is achievement of sufficient acreage of certified sources. For example, area of gene bases should create 2.5% of total forest stand area (Repáč 2008).

Table 2. Extant of the certified sources of forest reproductive material and amount of collected seed crop in Slovakia in 2015 (MPSR 2016).

Tree species	Certified stands	Gene bases	Selected trees	Seed orchards	Seed stands	Collected cones, seeds
	ha	ha	pcs	ha	ha	kg
Norway spruce	15,608	7,614	373	5.85	269.10	9,539
Silver fir	3,821	1,504	136	2.30	106.38	81,564
Scots pine	2,985	866	772	23.25	49.48	586
European larch	1,376	818	911	72.33	51.17	1,428
Oaks	9,130	2,106	504	1.00	58.04	54,569
European beech	31,984	6,384	37	0.00	183.50	227,074
Other	2,083	537	1,777	17.30	1.00	2,966
Total	66,987	19,829	4,510	122.03	718.58	368,187

Collection and transfer of FRM are regulated by *The Act no. 138/2010 on forest reproductive material* and *the Regulation no. 501/2010* of the Ministry of Agriculture and Rural Development of the Slovak Republic, which provides details on the production of FRM and its marketing. For the main tree species (Norway spruce, silver fir, Scots pine, European larch, European beech, English oak, sessile oak) *seed-collection (regional) zones* are specified. The seed-collection zones determine the place of origin and use of FRM for reforestation respecting the site conditions and phenotype features of species. Horizontal transfer of FRM within the zone of its origin is not limited. Use of FRM of out-off-respective zone origin is denied. Vertical transfer is limited by *forest vegetation (altitude) zones* (Table 3). Transfer of FRM to one degree higher forest vegetation zone than zone of collection of FRM, with agreement of Government Supervision Authority for FRM (the organizational unit of Forest National Centre) the possibility of transfer by two zones higher is allowed. This rule of vertical transfer is valid also for the other tree species, horizontal transfer is not limited. State-owned *Specialized Forest Enterprise called Semenoles* carries out collection, processing, storage and pre-seeding preparation of forest tree seeds for all owners of forests in Slovakia. Equipment of company BCC AB (Landskrona, Sweden) is used for seed processing of coniferous tree species. The enterprise provides strategic resource of seeds and is liable for development of breeding activities and conservation of gene pool of forest trees. The enterprise is a member of International Seed Federation since 2009.

Table 3. List of forest vegetation zones in Slovakia.

Forest vegetation zone	Altitudinal range (m a.s.l.)
Oaks	< 300
Oaks, European beech (dominance of oaks)	200 – 500
European beech, Oaks (dominance of beech)	300 – 700
European beech	400 – 800
Silver fir, European beech	500 – 1 000
Norway spruce, Silver fir, European beech	900 – 1 300
Norway spruce	1 250 – 1 550
Dwarf pine	> 1 550

The National Forest Centre (NFC) is the body appointed to oversee the collection, production and handling of FRM. It conducts an inspection in different activities: the management practices in seed orchards, the compliance with provenance principles, FRM transfer and correctness of records confirming the origin of forest stands, nursery practices and trading practices. The International Seed Testing Association (ISTA) accredited seed laboratory of the NFC performing the tests of seed quality according to *Slovak Technical Standard* "STN 48 1211 – Collection, quality and quality tests of forest tree fruits and seeds" (e.g. germination tests, seed purity tests, vitality tests, water content test). In addition, NFC administrates the national register of the certified seed sources.

3.2 Nursery practices

Planting stock of the most important and prevalent forest tree species is at present wholly produced by *generative propagation*. The exception is *autovegetative propagation* (via stem cuttings) of some species of genus *Populus,* cultivars of euro-american crossbreeds of *Populus* and some species of *Salix* occurred in southwest and southeast lowlands of Slovakia. *Heterovegetative propagation* is the method used for production of stock needed for establishment of clonal seed orchards (Paule 1992). Crucial portion of seedlings production is concentrated to 11 nursery centers in the state ownership, production area (major part serving for transplanting of seedlings) of which vary from several hectares to several tens of hectares. Seedlings are grown as bareroot or container-grown stocktype. Besides, over 200 small nurseries (size around 1 ha) in various non-state ownership produce only bareroot seedlings grown in the open beds.

3.2.1 Bareroot seedlings

Bareroot seedlings are grown either a) in strips or broadcast in mineral soil bed or b) broadcast in open or in greenhouse peat-based substrate bed. Bareroot seedlings of plantable size of a faster growing tree species with tap root (European beech, sessile oak, pedunculate oak, Scots pine, European larch) are produced in mineral soil in a 1−2 year rotation either with intact or undercut roots. In less favorable soil or climate conditions, time of growing of such seedlings may be one year longer. In the case of needs of better developed seedlings, especially of their root systems, transplanting of seedlings of the above mentioned species is not infrequent.

Bareroot seedlings are increasingly grown in open and greenhouse beds filled with peat-based substrates. In these conditions, seedlings of faster growing species should achieve plantable size after first growing season. Norway spruce seedlings are produced in a 3–5 year rotation, when 1 or 2 years are grown in peat-based substrates (in greenhouse or in open bed, respectively) and then transplanted to mineral soil and further grown for 2–3 years. Growing of silver fir bareroot seedlings under greenhouse conditions contrary to other species does not accelerate their growth. Production cycle of seedlings of silver fir is 1–2 years longer (2−3 + 2−3) than that of spruce.

3.2.2 Container-grown seedlings

As usual in many countries producing seedlings of the same tree species as in Slovakia, seedlings are mostly grown in *plastic trays* (e.g. Plantek F, Hikko, Quick pot) and in peat tablets Jiffy 7 Forestry under greenhouse conditions. Usual size of greenhouses for production both bareroot and container-grown seedlings is 50 m length and 9 m width (Fig. 5); a few greenhouses of several times larger capacity with fully regulated environment were recently built in a nursery centers in the state ownership. One-year-old seedlings of broadleaved species, Scots pine and European larch, 1.5–2-year-old of Norway spruce and 3-year-old of silver fir are planted on routine restoration sites. Of course, regardless of seedlings' final age, the seedlings are in suitable time (2–2.5 months after germination) removed from greenhouse and placed outdoor for hardening and additional growing. Container-grown seedlings of larger size are produced by transplanting of bareroot seedlings to containers of larger volumes of various shape and material. Very good guide for use and choice of new containers in Slovakia could be „Catalogue of biologically verified containers“, published and supplemented by Forestry and Game Management Research Institute of Czech Republic (Jurásek et al. 2006), because of very similar tree species composition and environmental conditions.

Figure 5. Greenhouse (size 50 × 9 m) for production of bareroot and container-grown seedlings in Slovakia.

3.2.3 Seedlings quality

Quality of seedlings is estimated according to their genetic, morphological and physiological traits (Leugner et al. 2009; Gömöry et al. 2010). At the present time, only *genetic aspect* is consistently take into account in nursery practice via keeping of the rules of the record and utilization of seedling origin ordered by Act on FRM. *Morphological quality* is assessed according to stem height, root collar diameter and visual evaluation of above-ground part and root system and their mutual proportions. Size and description of morphological traits stated in the respective *Slovak standard regulation* "STN 48 2211 – Seedlings of forest tree species" (Table 4) are unfortunately considered only as recommendations, not compulsory standards. Individual assessment of planting stock quality in each producer – client trade is determining. Higher probability of using of stock of lesser quality is in a case of directive supplies of seedlings from nursery to planters within an organization unit. *Physiological quality* of seedlings is operationally assessed only by visual appraisal of their freshness – assumption of foliar coloration, water content in roots, shoots and buds. As heartwarming may be considered the fact that roots of seedlings after lifting are in increasing rate protected against drying by application of hydrogels.

3.3 Reforestation practices

Determining principles of using of FRM for reforestation are that FRM is collected from certified source, registered by Government Supervision Authority and meets the rules of The Act on FRM for transfer of FRM. Below are briefly described some basic reforestation practices beginning by planning of reforestation and ended by post-planting care for plantations.

Table 4. Basic morphological parameters of standard seedlings of selected tree species used for reforestation.

Tree species	Seedlings								Transplanted seedlings					
	Height (cm)								Height (cm)					
	10-14		15-25		26-50		51-80		15-25		26-50		51-80	
	RCD (mm)	Max age	RCD (mm)	Max age	RCD (mm)	Max age	RCD (mm)	Max age	RCD (mm)	Max age	RCD (mm)	Max age	RCD (mm)	Max age
Norway spruce	-	-	4[1]	2	-	-	-	-	-	-	4	3	4	3
Silver fir	-	-	-	-	-	-	-	-	-	-	4	3	5	3
Scots pine	3	2	4	2	-	-	-	-	4	3	5	3	6	3
European beech	-	-	-	-	5	2	-	-	4	2	5	4	6	4
Sessile oak	-	-	-	-	-	-	-	-	4	2	7	2	7	2

[1] only container-grown seedlings
Abbreviations: RCD – root collar diameter, Max – Maximal.

3.3.1 Planning of reforestation

Program of Forest Care ("Program") is informative and executive document providing instructions for forest management practices carried out by foresters. "Program" is made by professionally skilled persons (owners of respective license) for constant forest territorial units (area 5–10 thousand ha) and is reworked every 10 years. For purpose of forest management, this large unit is separated to many small units (forest stands, area of each 3–10 ha). Description of natural conditions, dendrometric characteristics, felling, tending and restoration plan (for mature stands suitable for regeneration) are given for each forest stand in the "Program". *Restoration* *plan* contains restoration period, tree species composition (%) at the end of stand restoration and areas of both reforestation and natural regeneration for each species within a period of the validity of "Program". *Forest types of Slovakia* distinguished according to climatic and soil conditions qualified first of all via herbaceous layer composition is the main starting point for proposal of tree species composition (Hančinský 1972).

Changes of area of restoration sites are recorded separately for each stand throughout a year in "Restoration balance form". Within an *annual balancing*, restoration stand area at the beginning of a year is enlarged by areas which were accumulated (e.g. after felling, unsuccessful natural regeneration) and reduced by areas which were restored (by planting, natural regeneration). All felling areas are included to balancing of restoration, it means areas after planned felling in mature (felling age) stands and also areas after salvage felling in mature and pre-mature stands damaged or destroyed by accidental events (e.g. wind disaster). The state of restoration areas recorded in balance form at the end of a year is an initial state of areas in the beginning of the next year.

„Program of Forest Care" and balancing of restoration areas are basis for drawing up of "Annual reforestation plan" in the case of planned felling. In the case of salvage felling in stands in which is still not planned restoration in "Program", the guide for tree species composition proposal can be proposals in restored stands with similar natural conditions (the same forest type). "Management models" designed for larger units than forest stand are suitable background for proposal of tree species composition and their arrangement on the site, reforestation period and period to reach so called "lossproof" plantations. Important criterion to choose stands for reforestation for a next year is a year of occurrence of reforestation sites in order to keep the time determined by law for reforestation. For each of chosen stands, reforestation technique (planting, sowing), reforestation area (accuracy 0.01 ha), amount of seeds (kg) or seedlings (number) for each proposed species, and finally material, transport and salary costs are planned in "Annual reforestation plan".

3.3.1 Pre-planting site preparation

Mechanical, biological, chemical preparation or their combinations are alternatives for preparation of sites for planting. *Mechanical preparation* is carried out to allow easy movement on the site and to improve physical, chemical and biological soil properties, e.g.:

– Removing harvest residues (stumps, branches).

– Weed, non-required shrubs and trees control.

– Bedding (making of furrows) mostly on sand soils in plain fields for trench planting.

The next practices are made in a low range and increase of their use would be needful:

– Bedding, turf inverting, making of mounds and banks on weed, waterlogged and frost sites for turf or mound planting.

– Making of drainage network on continually waterlogged sites.

– Supplement of soil, making of terraces, spots, trenches, barriers (low fences, stone walls) on shallow gravel and rocky soils, steep and debris slopes.

Mechanical site preparation can be made either more or less sooner before planting (tillage, addition and stabilization of soil, technical adjustments), immediately before or at the time of planting or sowing. Removing of weed, debris, turf, or loosening of soil on a spot before digging out of planting hole or making of slit may be considered as pre-planting preparation. In terms of place size and work instruments, broadcast or spot, and manual or machine-made mechanical preparation, respectively is possible to use.

Biological site preparation means first of all use of nurse tree species which facilitate to targeted tree species. *Nurse trees*, in Slovak language named as make-ready, faciliting, pioneer or successive, serve for a purpose of soil stabilization, regulation of microclimate (mitigation of temperature extremes), improvement of physical, chemical and biological soil properties. One of the most known and utilized functions of nurse trees is their positive ameliorative effect on soil either through roots (drainage of soil profile), fallen photosynthetic apparatus (together with roots, amendment of soil by dead organic matter and after decomposition by nutrients) or transpiration ability to decrease excessive water content in soil. Nurse seedlings can be planted in advance or at the time of planting of targeted seedlings.

Some examples of nurse trees with an interest properties fit for planting site preparation are:

– Fast growth – *Alnus glutinosa* (L.) Gaertn*., A. incana* (L.) Moench.*, Betula, Larix decidua* Mill., *Populus tremula* L.*, Robinia pseudoacacia* L., *Sorbus;*

– Drought resistance – *Betula verrucosa* Ehrh.*, Fraxinus ornus* L.*, Pinus nigra* Arnold*, P. sylvestris* L.*, Quercus cerris* L.*, Q. pubescens* Willd.*, Robinia pseudoacacia, Tilia tomentosa Moench.;*

– Waterlogging resistance – *Alnus glutinosa, A. incana, Betula pubescens* Ehrh.*, Fraxinus angustifolia* Vahl.*, Populus, Quercus robur* L.*, Salix, Ulmus laevis* Pall.*;*

– Frost resistance – *Alnus, Betula, Populus tremula, Salix caprea* L., *Sorbus aucuparia* L.*;*

– Soil enrichment with organic matter – *Alnus, Carpinus betulus* L.*, Robinia pseudoacacia, Tilia, Ulmus.*

Chemical site preparation is applied on nutrient rich sites with intensive growing weeds, old clear areas after salvage felling or at change of coppice to seed-origin forest. Herbicides are used for removing of weeds, arboricides of non-required trees. This type of preparation is also made on whole area or spots of various sizes. Of course, pesticides must be used adequate period before reforestation. Remnants of weed are partly decomposed and do not hinder the later planted seedlings (usually next year). Sarvaš et al. (2007) consider that adjustment of soil pH and nutrient regime by liming and fertilization, respectively also belong to chemical site preparation. Fertilizers are applied to planting hole or on the surface in surroundings of stem at or after planting. Viewpoint of water and natural environment protection must be taken into account regarding to chemicals application.

3.3.3 Reforestation techniques

Seeding

Even though the respective standard regulation shows (apart from number of seedlings planted per hectare) also seed doses, reforestation by seeding in Slovakia is very infrequent. *Advantages of seeding* against planting are omission of seedlings production in nurseries, simplicity of technology and cheapness at the seeding time. High losses of seeds and seedlings, excessive seed depletion are the key circumstances for the benefit of planting. Seeding of broadleaved (oak, maple, ash, alder, birch, and rowan) more than coniferous tree species was used in certain rate in the past and is applicable also today. The reasons are more simply and cheaper collection of seeds of more often and rich fructifying broadleaves, but also higher demands of conifers for environmental conditions allowing seed germination and seedling survival.

Broadcast or spot seeding are alternatives regarding to seeding area. Broadcast seeding is less effective due to high cost for soil preparation and the need of large amount of seeds. Reforestation of e.g. large areas after salvage felling or non-forest soils by broadcast seeding of birch and rowan come into consideration. Large seeds (e.g. oak) are seeded into slit made by hoe. Smaller seeds (e.g. maple) can be seeded on spot (e.g. square 1 m^2) or strip after removing of debris and disaggregation of upper layer of soil. The most convenient *seeding time* is spring, enabling seeding to wet and loose soil and seed germination in a short period. Probability of seed damage and destruction is higher after autumn seeding and during winter. Good experience with seeding of birch on melting snow in late winter, providing adequate moisture for seeds germination is very interesting.

Planting

The basic planting techniques are a hole and slit planting. In relation to soil surface, seedling position after planting can be above, below or at the soil surface. The *hole planting* is the most used planting technique; it is appropriate for all kinds of soils and seedlings. Size and depth of the hole must be adequate to size of root system. The holes are dug manually by hoe or seldom by engine hole digger.

In applicable conditions, planting of seedlings to slits made by planting bar (*slit planting*) is more productive than the hole planting. Slit planting is applicable on most types of soil with exception of rocky or waterlogged soils. In Slovakia, this technique is use in a relatively large scale. Seedlings of smaller size with vertically arranged root systems are planted by this technique. *Trench planting* is not an extra technique but hole or slit planting on the bottom of furrow or trench. The reasons for the use of trench planting are to provide protection of seedlings against wind and solar radiation and to improve microclimatic conditions and water accessibility. This technique is used for planting of small Scots pine seedlings by machine planter to sandy soil on lowland of southwest Slovakia. Further mentioned techniques are used in a very small scale. *T-notch planting* is possible to use on the soils grown up enough by turf grass. Place for planting (notch) is shaped by hoe-axe tool or special hoe. Seedlings with horizontally arranged roots (Norway spruce) are planted by this technique but despite that root deformations are probable. *Mound and turf planting* are applied at reforestation of weed, waterlogged and frost sites. Seedlings are planted onto the top of soil mounded on site surface or onto inverted turf. Stabilization of mounded soil is needed (by stones, turf), what is labored and time-consuming. The most profitable way to prepare inverted turf is plough-up the furrows.

Spring planting time is suitable for all tree species. Planted seedlings should be in dormant state. *Autumn planting time* is recommended more for broadleaves than conifers and till root growth is not ceased. Container-grown seedlings increase flexibility of planting time. The base planting technique of container-grown seedlings is the hole planting. The use of planting tube in Slovakia is very rare.

Minimal *number of seedlings and seeding doses* according to tree species and forest function (wood-producing – Table 5 and protective forests – Table 6) are stated in the respective *Slovak standard regulation "STN 48 2410 – Reforestation and care for* *plantations"*. Regular square spacing is preferred in wood-producing forests. In protective forests, more favorable microhabitats with the accumulation of humus and humidity for good establishing and growing are utilized; therefore regular spacing is replaced by an average distance of individuals. Biological (tree species, environmental conditions, seedling size, function of plantation and others) and economical aspects (planting, plantation care and tending costs, production of timber assortments and others) are needed take into account to determine number of seedlings planted on particular site. The use of minimal in standard recommended number of seedlings in the case of saplings and container-grown seedlings is feasible. Economic reasons for low number of seedlings per ha should not exceed a limit of biological and function demands. The term *tree species mixture* express distribution of two or more tree species planted on planting site including size and shape of area planted by each species. Followed mixture types of species are defined based on layout and size of single area of species forming the mixtures: single mixture (alteration of species from hole to hole), small group (to 0.02 ha), group (0.03–0.20 ha), small island (0.21–0.50 ha), areal (0.50 ha and more) and in line mixture (one or more lines of one species is altered by line(s) of another species).

Table 5. Minimum number of seedlings and seeding doses of selected tree species for reforestation in wood-producing forests. Spacing is the same for planting and spot seeding.

Tree species	Site characteristics	Seedlings Thousands ha^{-1}	Seeds kg ha^{-1} (Number per spot)	Spacing (m)
Norway spruce	fertile, moist, mountain	2.0	0.09 (5)	2.2 × 2.2
	other	2.5	0.11 (5)	2.0 × 2.0
Scots pine	acidic and exposed	7.0	0.18 (4)	1.2 × 1.2
	fertile and moist	8.0	0.15 (3)	1.1 × 1.1
	mountain	4.5	0.18 (4)	1.5 × 1.5
Sessile oak	acidic and drying	7.0	55.0 (3)	1.2 × 1.2
	fertile and moist	9.0	47.0 (4)	1.1 × 1.1

Table 6. Minimum number of seedlings and seeding doses of selected tree species for reforestation in protective forests. Distance is the same for planting and spot seeding.

Tree species	Protective function	Seedlings Thousands ha^{-1}	Seeds kg ha^{-1} (Number per spot)	Distance (m)
Norway spruce	soil protection	3.0	0.13 (5)	1.8
	riparian stands	2.5	0.11 (5)	2.0
	avalanche control	2.5	0.11 (5)	2.0
Scots pine	soil protection	6.5	0.20 (5)	1.2
	anti-deflation	8.0	0.25 (5)	1.1
	riparian stands	5.0	0.16 (5)	1.4
	avalanche control	5.0	0.16 (5)	1.4
Sessile oak	soil protection	5.0	40.0 (2)	1.4

3.3.4 Post-planting care

Weed and game control are the most important and performed post-planting care operations. Removing of the non-required shrubs and trees and pine weevil control are carried out in any cases and regions in a distinctly smaller range. However, schematic removing of tree vegetation can be contra-productive in any situations in relation to their nurse effects. Insecticides were wholly applied until recent times in pine weevil control, but mechanical control (Mattsson 2016) is used in increasingly larger scale in several last years. The extent of post-planting care increased in major operations in the period 2010–2015. In 2015, weed and game control treatments were conducted on the area 48,000 ha and 40,400 ha, what is by 30.8% and 35.1% more, respectively than in 2010. Game control by fencing was used on the area 569 ha in 2015 (by 56% more than in 2010) (MPSR 2016). Perhaps this will have got a positive effect on the development and vitality of plantations.

Weed control

Weed deteriorates survival and health state, slowing down the growth and increase disposition of seedlings to damage by others detrimental agents (pathogen fungi, drought, snow, rodents). However, weed can has also positive effects, e.g. protection of soil against erosion, overheating or drying, source of organic matter, carbon cycling (Vakula et al. 2012). *Biological weed control* involves arrangement of effective tree species mixtures, planting of shelter trees or planting of seedlings of larger size. Planting should be carried out as short time as possible after open up the site. In Slovakia, *mechanical weed control* is predominantly used (90% of sites) because of its simplicity and less difficulty. Labor and time consumption and short-time efficiency are the negatives. *Weed cutting* is major method of mechanical control. In dependence of weed type and light demand of seedlings, weed cutting on spot (nearest seedling surrounding), seedlings strip or whole site are alternatives. When weed can provide shielding for seedlings, it is not cut tightly above soil surface, but higher at leading shoots of seedlings. Weed is cut either manually (hook, grass hook) or by mechanized way (engine scrub-cutter). Hoeing is welcome on spot around the seedlings in the first half of growing season of seedlings planting. Hoeing aerate soil to appropriate depth in order to discontinue capillarity and protect the soil against the exceed drying. *Chemical weed control* means the use of herbicides with selective or total efficiency for restriction of growth or destruction of weed. Labor productivity of this method is several times higher than of mechanical control, whereby effect of treatment last at least two growing seasons (Vakula et al. 2012). Only herbicides listed in the „List of authorized substances for protection of plants“ issued by Ministry of Agriculture and Rural Development is allowed for the use. Point or spot application of herbicides is recommended. The most usual way of application of herbicides is by back sprinkler.

Game control

In terms of forest management, game is significant damaging factor and its negative effect has an increasing tendency in recent years (Finďo and Maľová 2009). The most damage is caused by deer, roe deer, fallow deer, mouflon, wild boar, as well as rodents. *Preventive arrangements* are the basis for forest protection from damage caused by game − the appropriate forest management (mixed stands of indigenous trees, browsing trees, avoidance of rare species planting attractive for the game), maintenance of the game standard stock, appropriate care for animals and their habitat (game food plots, feeding, winter habitats). The young plantations in high range from 40 to 120 cm are especially sensitive to biting off and require specific attention (Finďo and Petráš 2007). According to *Slovak standard regulation* "STN 48 2441– Forest protection against game damage" the protective arrangements include *mechanical, biotechnical and chemical (biochemical) methods*. The most commonly used are:

− Fencing – the most expansive but most effective mechanical method, used only in localities with enormous game attack (winter habitats, near the feed rack).

− Individual mechanical protection – implemented by using various organic and inorganic materials (wraps, sheep wool, tin foil, the plastic sleeve etc.).

− Repellents – biochemical method of individual protection, composed of one or more active ingredients, excipients and inert mineral fraction, a long term effect on the game sensory organs (smell, taste and touch), applied most often by paint (brushes or PVC gloves with textile lining). Unequivocally the most used game control method in Slovakia.

3.3.5 Monitoring of outplanting performance

Chief of the lowest organizational unit (e.g. forest district in the state-owned forests) or by him authorized workers assess survival and a complex condition of all plantations to the end of year in which the plantations were planted. Authorized workers of higher organizational units assess a part of reforested sites. In the period 1997–2005, the state of the *sites after first planting* (within 2 years after occurrence of the clear site aimed for reforestation) and of *"lossproof" young stands* (after the maximal period given for their post-planting care – within 5 years after first planting) were evaluated by local forestry government authorities. The results of the evaluation served for the correction and improvement of the recognized plantation status if needed and also for allocation of (to the results adequate) government financial support for silvicultural activities. Since 2005, after the new Forest Act has been passed, the evaluation of plantation quality has not been already such consistent and self-dependent process, even though it is still made by local government authorities within inspection of forest management activities. The important change has been also differentiation of period for post-planting tending of plantations to 2−10 years in dependence of environmental conditions.

Sites after first planting should meet following criteria:

– Keeping of time determined for beginning of the site reforestation.

– Coincidence of site area recorded in forest administration record with really reforested area.

– Meeting the tree species composition prescribed by Program of Forest Care.

– Meeting the prescribed system of forest management in relation to forest restoration (in principal shelterwood or clear-cutting system).

"Lossproof" young stands should meet following criteria:

– It is composed of site-suitable tree species.

– It is formed with sufficient amount of evenly distributed (spread) well-developed individuals without a distinctive damage.

– It is sufficiently adapted to environmental conditions, what is indicated by adequate height increment.

3.4 Research activities

In the last decades, several progressive nursery and reforestation practices have been tested in Slovakia in experimental range in order to contribute to the effort to improve a complex quality of planting stock and success of reforestation. A brief outline of some examples of research activities are further pointed out.

3.4.1 Nursery

Seed germination, seedling emergence and development should be stimulated by soaking in solutions or by coating (incrustation, pelletizing) of small-size seeds with various coating mixtures, by various types of radiation, organic and inorganic acids (Šmelková 2004). Very good ability of spontaneous rooting of Norway spruce winter stem cuttings in appropriate conditions was confirmed (Repáč 2006; Repáč et al. 2011a). Micropropagation may be a perspective method of vegetative propagation of temperate noble hardwoods (Ďurkovič and Mišalová 2008). Some aspects of cultivation of container-grown seedlings have been tested (Šmelková and Tichá 2003; Sarvaš et al. 2005; Repáč et al. 2014). Interest of research was also focused on estimation of effects of growth substrates (Slávik 2005; Repáč 2007; Repáč et al. 2014), light regime (Sarvaš et al. 2005) and frost resistance (Sarvaš 2004) on seedling development and quality. Physiological response of seedlings to water stress holds recently attention of forestry research (Ditmarová et al. 2010; Pšidová et al. 2015).

Interesting tool bringing progress in planting stock production technologies aimed to improve seedling quality is application of various natural and synthetic materials and products, called soil conditioners. Application of natural organic material (Repáč 1996a), hydrogels (naturally degradable water-retaining granules) (Takáčová et al. 2007) and bio-stimulants (produced on the basis of synthetic amino acids) (Slávik 2005) have potential to stimulate seedling emergence, survival and/or growth. Inoculation of nursery-grown seedlings with selected fungal and bacterial strains is perspective. Series of experiments concerning with testing of effects of artificial mycorrhization of Norway spruce and Scots pine seedlings and spruce cuttings with laboratory produced vegetative inoculum of ectomycorrhizal (ECM) fungi (Repáč 2011) were carried out in Department of Silviculture of Technical University in Zvolen (Repáč 1996b, 2003, 2007; Repáč et al. 2011a, 2013a). Commercial fungal and bacterial and other types of products were tested in the last years (Tučeková 2007; Repáč et al. 2011a, 2014). In agreement with findings of other authors (González-Ochoa et al. 2003; Corrêa et al. 2006; Buraczyk et al. 2012), the results of mentioned nursery inoculation experiments were inconsistent, in dependence of variable effects of a particular microorganism–tree–environment relationships of the unique operational experiments. Nevertheless, the results encourage us to further investigation and a future utilization of beneficial microorganisms in forest trees production. Although the goal of ECM inoculation in a nursery is formation of ectomycorrhizae and biological control of root pathogens, the example of possibility of seedling growth stimulation with applied ECM fungi is shown in Figure 6.

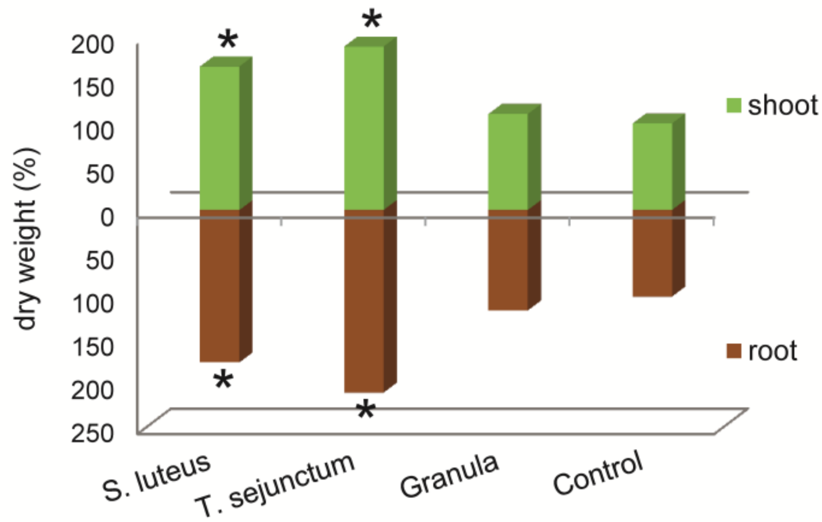

Figure 6. Shoot and root dry weights of 1-year-old bareroot Scots pine seedlings inoculated with mycelial-bead inoculum of ectomycorrhizal fungi *Suillus luteus* and *Tricholoma sejunctum*. The weight is expressed in percentage of the mean values of the control seedlings. Granula – beads lack of mycelium. Data with asterisk are significantly (P=0.05) different from control.

3.4.2 Planting sites

Experimental testing of less frequent procedures with potential to improve results of routine spring planting of bareroot seedlings seems to be very useful, especially on water, nutrient and microbial deficient sites. Water sufficiency in soil is crucial determinant of survival, nutrient uptake and growth of seedlings after outplanting. Natural organic matter (forest soil, peat, composted bark), synthetic hydrogels and various water absorbing materials (e.g. Alginit, Zeolit) applied on seedling roots or to planting holes can improve soil and root water balance and thus support seedling development (Tučeková 2004a, 2013a; Sarvašová and Ferencová 2009; Jamnická et al. 2013; Repáč et al. 2013b, 2016; Repáč and Vencurik 2015). Fertilization with organic-mineral fertilizers (Tučeková 2013b), slow-released fertilizers (Tučeková 2004a; Repáč and Vencurik 2015) or application of wood ash (Tóthová 2007) are very beneficial nutrients supply treatments especially on degraded, nutrient poor and by air pollutants contaminated sites. Repáč and Vencurik (2015) highlighted the need of increased caution at application of fertilizers, because inadequate application or oversize doses can induce damage or mortality of seedlings.

Similar as in the nursery experiments, commercial fungal and bacterial products have been tested on experimental planting sites in Slovakia, with variable effects on outplanted seedlings (Tučeková 2004a; Repáč et al. 2011b, 2013b; Repáč and Vencurik 2015). Effects of applied additives on survival, drying of leading shoots, growth, eventually content of basic nutrients in photosynthetic apparatus of seedlings were variable – mostly indifferent, but in more cases also slightly to significantly stimulated, in dependence of tree species, soil properties of experimental sites and a weather course during period of the experiments.

The best opportunity to eliminate deterioration of seedling roots and adverse soil properties is the most probably the use of container-grown seedlings. Container-grown seedlings survived and grew better and suffered lesser by shoots drying than bareroot seedlings (Tučeková 1999, 2004b; Šmelková and Tichá 2003; Repáč et al. 2011b, 2016). However, planting of seedlings of too small size was not successful (Repáč et al. 2011b; Tučeková 2013b). Apart from other advantages, container-grown seedlings should be less sensitive to planting time than bareroot ones. In spring, the most suitable planting time, management problems or unfavorable weather (low precipitation, high temperatures) can cause decrease of survival rate of outplanted seedlings. Seedlings can be successfully planted along spring also in an autumn time (Gubka 2001; Repáč 2015). Repáč and Vencurik (2015) reported preliminary results of experiment dealing with underplanting of silver fir under Norway spruce stand, a restoration method of great potential to contribute to reconstruction of deteriorated spruce ecosystems. So called seeding to vegetation cells, technique previously tested in Czech Republic (Mauer et al. 2005) appears to be a perspective technique for reforestation even large windthrow areas with adverse environmental conditions (Tučeková 2011). Within scope of post-planting care no intensive research has been made, nevertheless the comparison of various methods and materials used for weed control by mulching (Maľová and Longauerová 2012) is example of any activity.

3.5 The Rural Development Program 2014-2020

The ongoing Rural Development Program 2014–2020 is oriented on:

– Better use of the potential of the country to maximize CO_2 sequestration in agriculture and forestry.

– Prevention of natural disasters in the forests, strengthening the protective function of forests and reforestation following natural disasters.

– Elimination of impacts and adaptation of agriculture to climate change.

– Promoting resource efficiency and supporting the shift towards a low-carbon economy and climate resilience in the agriculture, food and forestry sectors.

– Land consolidation will be carried out in accordance with the terms and conditions of environmental protection and the creation of a territorial system of ecological stability.

– First afforestation of agricultural land.

At the same time, it has to be paid ongoing commitments from previous programs. From the shortened programming period 2004–2006, sixteen projects of afforestation of agricultural land have continued, and from the period 2007–2013 nineteen projects.

4 Future perspectives

From our point of view, reforestation perspectives represent progressive nursery technologies producing high quality seedlings, planting techniques and treatments, and particular reforestation programs supporting sustainable management of forest ecosystems facing climate change. In recent times, the effort of researchers in Slovakia has focused on nursery and outplanting treatments considered to be perspective and useful for performance of reforestation tasks in a short- but also a longer-term perspective. In relation to research activities introduced in previous section, the partial aims of Slovak government authorities and foreign research and practices, some ideas regarding reforestation possibilities, needs and perspectives in Slovakia are mentioned in this section.

4.1 Sources of forest reproductive material

Insufficient range and uneven distribution of FRM sources of tree species according to the transfer zones have negative consequences in the case of unplanned tasks of reforestation after large accidental forest disturbances.

The steps helpful for improvement of this situation are:

− The most important source of FRM should be certified mature stands of high phenotype quality, which are the most occurring and genetically diversified source.

− Sufficient basis of certified stands should be 10% part of area of fructified stands in the range of natural occurrence of respective tree species. This idea is fulfilled now neither for Norway spruce nor European beech, the most spread and important species in Slovakia.

− Increase of area of FRM sources in the transfer and vegetation zones where they are inadequately present.

– Establishment of seed orchards of tree species with a small range of this category of FRM source. Uneven distribution and excessive range of seed orchards of Scots pine and European larch in some zones must be balanced along the culmination of production of the existent orchards.

– Planning of FRM requirements for several years in advance; creation of a seed stock.

– Creation of an information system that would allow information about available FRM.

− Revision of the current zoning in the case of more distinctive changes in the distribution of tree species due to climate change.

4.2 Nursery perspectives

4.2.1 Integrated approach

One of possibilities to improve survival and growth of seedlings during the first post-planting years is improving the quality of nursery-grown seedlings. Integrated (complex) approach in growing of and care for planting stock is important tool to achieve high morphological and physiological seedlings quality. Although the use of pesticides (pest control) and fertilizers is very important element of production process, the base principle of integrated approach is *preventive activities against stress agents* weakening seedling vitality (e.g. early-spring seeding, use of fresh, fumigated growth substrates free of pathogens, appropriate seeding doses and seedling density). Integrated approach means also e.g. *consistent regulation of growing environment* (temperature, humidity) and *keeping the best time and quality of all steps, procedures or activities* made within technological and biotechnological procedures. More of these operations are not unfortunately carried out consistently in Slovak nurseries today. For example, the present state of construction and equipment of most greenhouses does not enable the first prerequisite of effective growing of high quality seedlings – comprehensive and reliable regulation of environmental conditions in a greenhouse. An innovative technology for production of seedlings based on a short pre-cultivation period in a growth chamber at high seedling density followed by automatic transplanting to containers has been started in Sweden (Mattsson 2016). This high-productive but relatively high investment and operational costs consuming technology has not realistic possibility of applying in Slovak conditions. A few large conventional plastic greenhouses with fully regulated substrate and climatic conditions enabling cultivation of two seedling batches per year were recently activated. Construction of such several additional greenhouses and exchange of the less functional, older ones would be very needful.

4.2.2 Physiological quality of seedlings

Physiological quality is crucial for adaptation of seedlings to environmental conditions especially of adverse planting sites (Jurásek et al. 2010; Ditmarová et al. 2010; Grossnickle 2016). *Seedlings have to be protected against drying* from lifting in nursery to planting on site. This demand can be conducted by proper manipulation and also by application of substances prohibiting transpiration of above-ground part (anti-transpirants) and desiccation of roots (hydrogels). Larger attention must be further paid to such protection of seedlings in order to be planted with minimal reduction of physiological quality. *Perspective methods of evaluation of physiological quality* of seedlings for wide practical use should be measurement of stem, shoot or root electric conductivity, water content in plant tissues and chlorophyll fluorescence. We must pay more attention for evaluation of morphological and physiological quality in the future and knowledge of these features use more for consulting, investigating, inspecting and operational purposes. Lifting, sorting, distribution, other manipulation and planting of a large amount of seedlings produced in large nurseries in Slovakia in spring time are work and time consuming operations sometimes negatively affecting seedling physiological quality and reforestation result. One opportunity to reduce the spring impact of work is lifting and planting in autumn (Tučeková 1999; Barzdajn 2010; Repáč 2015), the other one winter storage in control conditions.

4.2.3 Long-term storage

The result of long-term storage of seedlings depends on many traits (Kozlowski and Pallardy 2002). Long-term storage may results in dehydration of seedlings, depletion of stored carbohydrates by respiration and decrease of root growth potential, and thus adversely affects survival and growth of outplanted seedlings. Abroad, considerable interest was dedicated to long-term storage of coniferous seedlings (Luoranen et al. 2012; Lindstrom et al. 2014). Different aspects of storage of deciduous species of temperate zone were investigated in a lesser extend; the results showed large variability of seedling response (e.g. Van Labeke and Volckaert 2010). A large part of production of several nursery centers in Slovakia is production of European beech – the most spread, ecologically and economically very important and recently the main species for reconstruction of damaged spruce ecosystems. Large-scale winter storage should be very useful contribution to enhance flexibility of lifting, handling and planting of beech seedlings. Long-term storage of beech was solved only exceptionally in experimental mode (McKay et al. 1999). Experiments focused on investigation of various aspects of long-term storage on physiological quality and outplanting performance of beech seedlings, conducted by Technical University in Zvolen in cooperation with staff of government-owned nurseries have been started not long ago. In the case of obtaining and verification of positive results, their immediate utilization in operational scale is very feasible.

4.2.4 Inoculation by beneficial microorganisms

Application of beneficial microorganisms (*ectomycorrhizal and to pathogens antagonistic fungi, soil bacteria*) is perspective method of improvement of physiological quality of seedlings and also of biological control against soil pathogens. Growth stimulation of seedlings is another welcome potential effect of inoculation. Many authors confirmed positive effect of inoculation of seedlings with ECM fungi and soil bacteria on seedling adaptive ability (Marx 1991; Bending et al. 2002; Enebak and Carey 2004; Penanen et al. 2005). The most useful known benefit of ECM symbiosis for forest trees can be increased nutrient and water uptake. Although nursery-grown and outplanted seedlings on major restoration sites in Slovakia are spontaneously colonized by ECM fungi (Repáč et al. 2013a; Repáč and Vencurik 2015), artificial mycorrhization of adequate amount of seedling nursery production by selected efficient ECM fungi aimed for reforestation of drought, nutrient and ECM fungi deficient soils is very required in near future. *Adjustment of nursery cultivation practices* is needed (fertilizers and pesticides doses, temperature, humidity and light intensity regimes) in order to achieve higher probability of potential success of inoculation. However, because the unique biological phenomenon, *the use of beneficial microorganisms does not guarantee that inoculation will be always useful to plants*. Result of inoculation depends on many circumstances (inoculum and inoculation patterns, host–microorganism–environment interactions) and even in the case of successful nursery inoculation, seedling outplanting performance depends in a great extent on unpredictable climate factors of planting sites. These inoculation difficulties and hazards and absence of consistent results are till now the reasons for skepticism to ECM and bacterial inoculation in nursery and reforestation practices in Slovakia.

4.2.5 Vegetative propagation

Regarding to unsatisfied resistance, health and excessive damage of forests in some regions of Slovakia, vegetative propagation should have increasingly greater importance for *preservation and reproduction of valuable, endangered and resistant populations* of forest tree species (Leugner et al. 2011; Repáč et al. 2011a). Among the most spread and important forest trees, Norway spruce demonstrates the best rooting ability of stem cuttings (Fig. 7). As ECM fungi produce auxins, artificial mycorrhization of relatively sterile rooting substrates can improve process of rhizogenesis and quality of root systems (number of fine roots and ectomycorrhizae) of rooting cuttings. After outplanting, inoculated Norway spruce rooted cuttings reached almost 100% survival rate and relatively fast growth, and distinctive plagiotropic growth in the nursery was continually repressed on planting site and morphology of the rooted cuttings was comparable with seedlings 4 years after planting (Repáč and Vencurik 2015). The use of vegetative propagation for establishment of wood-produced forest would come into account only in the case of tree breeding aimed for improvement of wood production and quality. *Combination of vegetative and generative stock* of more tree species is suitable from point of view of health and resistance of forest stands. *Micro-propagation is perspective method* for acceleration of breeding programs and in distant time horizon also for production of planting stock for reforestation (Ďurkovič and Mišalová 2008). This biotechnology allows utilize one micro-part of plant for reproduction of many identical plants in control cultivation conditions in relatively short time. Special facilities with opportunity to control environmental conditions would have to be constructed for rooting of cuttings and especially for micro-propagation.

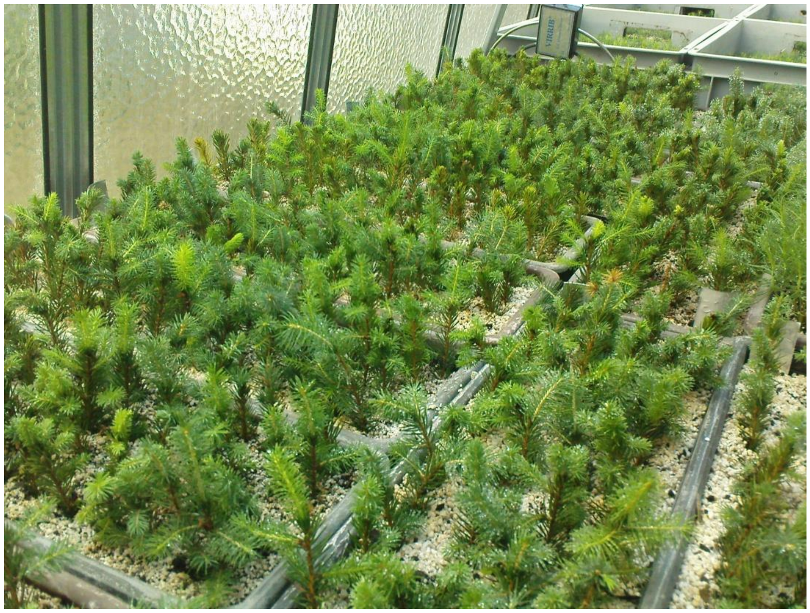

Figure 7. Rooting of Norway spruce stem cuttings.

4.3 Reforestation perspectives

4.3.1 General background

Even though very variable environmental conditions of reforestation sites in Slovakia due to diverse horizontal and vertical relief, the incorporation of the principle of *Target plant concept* (Dumroese et al. 2016) would be the most useful biological and management tool of reforestation programs in the forests facing climate change. Target plant concept emerge from the idea of “fitness for purpose” (Sutton 1980) and means that plant quality does not mean how a plant appears in the nursery, but its outplanting performance. This concept should be implemented in a short time at least to reforestation principles of large, relatively homogenous clear sites following disturbances, in Slovakia typically windthrow areas. Regarding types of *reforestation projects* summarized by Ivetić and Devetaković (2016), reforestation of such vast clear sites relate to site specific projects, in which selection of the most appropriate species fitting in environmental conditions of planting site is essential for success. Although the possibility to use FRM for reforestation in higher vertical zones than a zone of FRM collection given in the Slovak FRM transfer rules might be considered as perspective action to expected species range shift due to climate change, till it is mainly used to facilitate compliance of FRM transfer regulation in the case of FRM deficiency in particular zone. *Assisted migration* within a species current range, but also just beyond or quite distant from its current range (species specific projects) is intentional movement of FRM facing climate change (Ivetić and Devetaković 2016). Development of a complex analysis and proposal of solution of probable forest tree species range drift scenario due to climate change including reforestation prospects and goals (species specific projects) would be very needful perspective restoration strategy of Slovakia.

4.3.2 Seedlings quality

Planting stress is the major limiting factor in restoration (Grossnickle 2016). Required seedlings' origin, high morphological and physiological seedling quality, careful performance of handling, planting and other operations can mitigate stress effect. Apart from the treatments mentioned in nursery perspectives section aimed to contribute to seedling *physiological quality*, other ones e.g. hardening practices and improved nutrition at planting through fall nutrient loading (Grossnickle 2016) can increase chance to overcome planting stress. Unfortunately, these practices are not made in Slovakia in operational rate at all and must be considered and be involved in perspective practices. Importance of basic *morphological attributes* (height, diameter, overall size, root to shoot ratio) on impact of stress factors to seedling outplanting performance is well known. The most adversely affecting factor became limiting and determining for selection of seedling morphology. For example, lower seedlings with higher diameter and root to shoot ratio are capable better withstand water stress on drought sites, higher seedlings suffer less and grow up faster from unfavorable effect of aggressive weed and ground frost. For illustration, 1-year-old Scots pine seedlings are the best material to survive in sandy dry soils of southwest Slovakia, but our results showed that larger transplanted seedlings of Scots pine and Norway spruce are better than smaller ones for reforestation of sites with different, variable environmental conditions (Repáč and Vencurik 2015; Repáč et al. 2016). Seedlings with higher portion of short roots and ectomycorrhizae, responsible for water and nutrient uptake should be used more widely for reforestation of drought and nutrient poor sites.

4.3.3 Handling and planting of seedlings

Although the basic principles of handling and planting of seedlings on planting sites are relatively simple and known, they are not made always correctly and consistently. Let's recall very briefly some of them. Bareroot seedlings are much more exposed to damage and incorrect technique of planting than container-grown material. Seedlings planted in spring time must be in the state of dormancy. Seedlings, especially roots have to be protected against drying not only during transport but also a short period before planting. If the cut down of large roots is needed, a cut surface must be as small and smooth as possible. Proper order and performance of planting steps has to be followed. It means mainly size and shape of hole or slit adequate to root system to avoid root deformation, seedling placed deep enough and sufficiently fixed in soil to reach the best contact between roots and soil. Though not directly related to planting technique, the importance of immediate and long-term monitoring of outplanting performance (Dumroese et al. 2016) is needed to be highlighted here. Monitoring in Slovakia (briefly described above) is carried out on acceptable standard but greater emphasis must be placed on its use to improve outplanting performance.

4.3.4 Container-grown seedlings

Container-grown seedlings have a greater potential to succeed at least in shallow, gravel to stony and nutrient degraded soils. Despite of well-known advantages and increasing production of container-grown seedlings, proportion of this stocktype is only not much over 10% of total seedlings production (Slovak Forests 2013), whereby unfavorable environment of restoration sites in Slovakia requires its higher proportion. The main reasons for insufficient amount of container seedlings are higher technological and economic difficulties of production process as compared with bareroot stock, thus higher seedling cost and immediate charges for planting. However, economic analyses in operational conditions showed that total charges at the end of post-planting care for plantations are by contrast lower as compared with bareroot stock planting (Bartoš et al. 2007; Tučeková 2011). This should be enough motivation for increasing demand and production of container-grown stock. On the other hand there is useful to accept that in spite of encouraging container-grown seedling field performance (Jurásek et al. 2004; Repáč et al. 2011a; Tučeková 2011), the use of this stock brings certain biological risks at any circumstances, such as mechanical damage or drying of soft shoots of broadleaved species after planting, greater attractiveness for wildlife or change of architecture up-to secondary deformation of roots on nutrient-deficient sites in consequence of oversize application of fertilizers in the nursery.

4.3.5 Planting time

Autumn planting time can be convenient opposite to *spring planting time* from organizational but also biological viewpoint. In spring, seedlings are often active in growth at planting due to reforestation management failure caused by a large amount of works and weather unpredictability. Seedlings planted in autumn renew root growth in spring immediately when allow soil conditions. Thereafter a risk of damage by drought and high temperatures is lower compared to spring planting. If seedlings planted in autumn will survive, growth advantage over those planted in spring is almost sure. Disadvantage of autumn planting can be damage by game and unfavorable weather course during winter. Till now, commonly accepted recommendation in Slovakia is broadleaved species and European larch can be planted also in autumn, coniferous species better just in spring. Based on experimental results and experiences, Kuneš et al. (2011) similarly consider autumn planting even more suitable than spring for broadleaves, conifers recommend to plant in spring. In contrast, Gubka (2001) found that Norway spruce seedlings planted on high-elevation site in autumn survived better as compared to spring time and Barzdajn (2010) found better growth of Scots pine seedlings from autumn than spring planting time. Results of our experiments (Repáč et al. 2011b, 2016; Repáč 2015) revealed a greater effect of surroundings of planting site than tree species on performance of seedlings planted in autumn and that *planting in autumn provides a satisfy survival and growth of seedlings* (including conifers) as compared to spring planting. The results suggest that autumn planting time could be more utilized in reforestation practices in Slovakia.

4.3.6 Hydrogels and ectomycorrhizal fungi application

Typical expressions of climate change are increasing temperature and a longer-lasting and sudden occurrence and changes of climate and weather extremes including long periods of high temperatures without precipitation. As a result, soil water deficiency and plant water stress are increasingly more frequent and severe. Thus practices aimed to decrease water stress of seedlings planted on potentially drought sites are actual and perspective. Application of substances with high ability to accumulate and subsequently release water (hydroabsorbents, hydrogels) and inoculation with ECM fungi belong to the most promising treatments intent on *mitigation of water stress* (Castellano 1996; Tučeková 2004a; Mauer 2007; Repáč et al. 2013b; Karličić et al. 2016). ECM inoculation and application of hydrogels on seedling roots are more efficient in nursery than on planting site. However, the treatments can be made without higher difficulties also in the field. Huge amount of commercially produced hydrogels is available. Hydrogels are applied obligatory in slurry formulation into the planting holes or root systems of seedlings are dipped into the slurry (Fig. 8). Compared to research-scale ECM inoculum formulations (mycelial-bead or mycelial-substrate carrier inocula), gel formulation prepared by diluting of mycelium and spores of ECM fungi in pure hydrogel is more appropriate use in a commercial scale. Product Ectovit (Symbiom s.r.o., Czech Republic) as an example of hydrogel and ECM inoculum combination was recently tested in experimental scale on planting sites (Holuša et al. 2009; Pešková and Tuma 2010; Repáč et al. 2011b, 2013b, 2016). The production and marketing of ECM inocula on a commercial scale increased recently and further potential appears to be quite large (Repáč 2011). Despite of relatively frequent use of hydrogels for operational purposes in Slovakia, their use in larger scale together with field ECM inoculation have a great potential to contribute to the success of reforestation.

Figure 8. Dipping of root systems of seedlings in hydrogel immediately before planting.

4.3.7 Seeding to vegetation cells

Seeding to so called vegetation cells appears to be perspective reforestation technique (Fig. 9) (Mauer et al. 2005; Tučeková 2011). Vegetation cells are from variable material, most often plastic, the best degradable one; size of cell is e.g. 8 × 15 cm (diameter × height). Several seeds are seeding to organic matter (e.g. peat) sprinkle on the bottom of seeding hole. The seeds are covered with proportional layer of suitable matter. Cell is placed on the hole and fixed by surrounding soil. The seeds can be protected against rodents with wire shelter attached to the cell top. Seeds and later seedlings have got created favorable conditions, without larger temperature and humidity oscillations. Seedlings of some species (oak, beech, larch, and alder) are 30–50 cm high after second growing season. Preliminary results suggest that technology has the potential to use for seeding of large seeds of broadleaves on adverse sites or in the case of planting stock deficiency after wind disasters.

Figure 9. European beech seedling four months after seeding to vegetation cell (height of cell 10 cm). Photo by A. Tučeková.

4.3.8 Underplanting

Underplanting is a silviculture tool focused on regeneration of trees necessitating a protection of old stand canopy and planting of which is impossible or very difficult on clearcut. In Slovakia, underplanting is of greater significance in the last years, particularly in connection with unsuitable stand structure, deterioration of health state and decline of functions of spruce forests in northern regions of Slovakia. One of the ways how to prevent the complete disintegration of the forest community can be the establishment of new plantations under cover of spruce stand at age 50–80 years. This method of stand transformation is ecologically and economically more effective than reforestation on large areas exposed to weather conditions. Tree species commonly used in underplanting are silver fir and European beech with addition of noble woods, mainly of maple. Since both, fir and beech belong to the category of shade-tolerant species their recovery under cover of outgoing spruce stand is very useful and perspective. Underplanted trees utilize mature stand for adaptation on environment and faster growth, thus ensuring continuity and high ecological stability of newly established stands. In addition, incorporation of beech and fir in pure spruce stands also improves soil properties and increases biodiversity (Ammer et al. 2008). Improvement of knowledge regarding to growth of underplanted seedlings in specific environment of disintegrating spruce stands can improve effectiveness of process of their reconstruction, performed in correspondence with principles of close-to-nature silviculture.

4.3.9 Restoration of spruce ecosystems

The current state of spruce stands is alarming. Spruce stands manage by traditional clear cutting method are productive but extremely vulnerable. Especially stands older than 80 years are subject to rapid and extensive break down. They face to strong disintegration and local total destruction. Destruction of the spruce ecosystems is caused by synergic effect of abiotic (wind, snow, drought) and biotic (insects, pathogenic fungi etc.) damaging factors (Schütz et al. 2006; Pittner 2012; Bošeľa et al. 2014). Wind disturbances with subsequent bark insect and/or fire impacts are the most often causes of the spruce stand destruction and followed large clear areas. Long-term deforestation eliminates productive and non-productive functions of spruce forests. Their restoration is very difficult under existing environmental conditions. At present, there is insufficient scientific knowledge to define treatments that would lead to clear solution of the Norway spruce decline. Some points of general approach to revitalization of spruce forests in Slovakia:

− Consistent implementation of preventive, protective and defensive treatments against bark beetles.

− Forest regeneration must be carried out with maximum use of native plant species, increased participation of broadleaves (approximately 40%) and complex implementation of the post-planting care and protection of plantations.

− Performance of other treatments related to the determination of the current state and preparation of the spruce stands for their regeneration.

5 Conclusion

Forest ecosystems are exposed to detrimental factors induced by climate change. Especially a frequent occurrence and change of climate extremes (drought, windstorm, snow) with simultaneous or subsequent damage of forests by bark insects have unfavorable impact to forests in Slovakia. These harmful factors probably in connection with long-lasting residual effect of air pollution induce synergistic effect that cause damage or total destruction mainly of spruce ecosystems. Decline of the spruce ecosystems may be considered as the most serious problem of forest management in Slovakia in the present times. This situation causes higher difficulties in reforestation, the prevalent way of forest restoration in Slovakia. Future reforestation results will be distinctly related to the ability to react and solve the challenges arising from climate change. Genetic, morphological and physiological seedlings' quality, handling and planting of seedlings, environmental conditions of planting sites, and care for plantations are the crucial circumstances affecting outplanting performance of seedlings. History and current state of nursery and reforestation practices in Slovakia supported by research activities are the good starting points to face the upcoming challenges. Despite of certain current and supposed problems mentioned in this review, nursery and reforestation managers and personnel believe in the promising future perspectives of reforestation in Slovakia.

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