Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems
http://dx.doi.org/10.5424/fs/2014232-04869

Forest Systems 2014 23(2): 273-288
ISSN: 2171-5068
eISSN: 2171-9845

Role of planting stock size and fertilizing in initial growth performance of rowan (*Sorbus aucuparia* L.) reforestation in a mountain frost hollow

Ivan Kuneš[1]*, Martin Baláš[1], Daniel Zahradník[1], Olga Nováková[1], Josef Gallo[1],
Jarmila Nárovcová[2] and Miles Drury[3]

[1] *Faculty of Forestry and Wood Sciences. Czech University of Life Sciences Prague. Kamycka 129. 165 21 Praha -Suchdol, Czech Republic.* [2] *Opočno Research Station. Forestry and Game Management Research Institute v.v.i., Strnady. Na Olive 550. 517 73 Opočno, Czech Republic.* [3] *National School of Forestry. University of Cumbria. Fusehill Street. CA1 2HH Carlisle, Great Britain*

Abstract

The aim of study: (1) to compare the survival rate, growth performance and nutrition of large and common-sized planting stock of rowan (*Sorbus aucuparia* L.) on a frost-exposed site and (2) to assess whether fertilizing had any effect on the plantations.

Area of study: The Jizera Mts., an area heavily disturbed by air pollution situated on the Czech-Polish border close to Germany

Material and methods: Two types of planting stock were tested in a mountain frost hollow on an acidic mountain humic podsol: (a) the bare-rooted saplings 131-140 cm tall and (b) common-sized containerized transplants 26-35 cm tall. One half of the saplings and common-sized transplants were left untreated and the other half were fertilized with a low dose (30 g per tree) of a slow release fertilizer based on methylene urea and potassium magnesium phosphate. Growth performance and nutrition of plantations were investigated.

Main results: Due to serious deformations and stem breakages inflicted by snow and frost, the prospects of common-sized transplants seem much worse than those of saplings. The height growth of saplings was significantly more rapid than that of common-sized transplants. As for growth, neither the saplings nor common-sized transplants did significantly respond to fertilizing. The effects of fertilizing on nutrition of rowans were unconvincing. The extreme temperature events during growth seasons and snow deformations in winters might be the decisive factors influencing growth performance of rowans under referred conditions.

Research highlights: On the frost-exposed sites, the height of taller saplings might partly compensate for a missing shelter of forest stand since the terminal leaders are above ground-frost zone.

Key words: mountain ash; sapling; common-sized transplants; nutritional status; temperature.

Introduction

The region among the north-western part of the Czech Republic, south-western Poland and eastern part of Germany encompasses a complex of border mountains (the Sudetes) supporting extensive forests and ecosystems important for the environment, forestry, water and landscape management of all three countries (Mazurski, 1999). However, this region includes also the largest brown coal basins in Europe (Filipiak and Ufnalski, 2004).

As a result of a rapid industrialisation after the World War II, the region was exposed to an enormous air pollution load and acquired the name "Black Triangle" (Akselsson *et al.*, 2004; Křeček and Hořická, 2006). Thermal power plants in the Black Triangle burned brown coal from local coal basins and emitted extremely high quantities of pollutants, mainly S and N

---

* Corresponding author: kunes@fld.czu.cz

Received: 15-08-13. Accepted: 20-02-14.

This work has three Supplementary Figures that do not appear in the printed article but that accompany the paper online.

Abbreviations: CS (control saplings); CT (control transplants); FS (fertilized saplings); FT (fertilized transplants).

compounds (Filipiak and Ufnalski, 2004; Hrkal *et al.*, 2009). Consequently, the chemical balance of sensitive mountain forest soils was upset and the Sudetes experienced a massive air-pollution calamity that disturbed forest ecosystems on extensive areas (Křeček and Hořická, 2001). Later in the 1990s the air pollution was significantly reduced thanks to a modernisation of power plants (Mazurski, 1999) and implementing the desulphurisation technologies (Fottová, 2003; Hrkal *et al.*, 2006). Nonetheless, the reconstruction and revitalisation of forest stands in the Black Triangle have been a long term task. The large-scale clear-felled tracts in the summit areas proved to be an extremely unfavourable biotope for replanting, since the sites lost a shelter provided by mature forests, their soils were depleted by acidification and colonised by *Calamagrostis villosa* (Chaix) J. F. Gmelin communities hindering the forest regeneration (Pyšek, 1994).

The Jizera Mts. (a part of the Sudetes) are typical representative of mountains in the Black Triangle. Their forest stands belonged among the most seriously damaged in the region (Lomský *et al.*, 2011). The total area of the clear-felled tracts in the Jizera Mts. amounted to 12,000 ha in the end of the 1980s (Balcar *et al.*, 2011). As a result of disintegration of forest ecosystems and intensive salvage harvesting the retention capacity of local watersheds declined, soil erosion significantly intensified and sediment runoff increased (Křeček and Hořická, 2001).

The improvement in the air pollution enabled foresters in the Jizera Mts. to replant the majority of clear-cut areas in the course of 1990s. However, there are still some sites, usually the most extreme, where the conventional replanting techniques failed. Moreover, the new "post-calamity" generation of forests remained dominantly coniferous, although costly efforts were being made to include more deciduous trees (Mazurski, 1999) and silver fir (*Abies alba* Mill.) that were in the natural forests significantly more abundant. On frost-exposed mountain forest sites, the common-sized planting stock often suffers from ground frosts in the most vulnerable initial phase after planting. This phenomenon frequently results in a post-planting shock manifesting itself in growth stagnation (Kuneš, 2003; Balcar and Kacálek, 2008) or even increased mortality rate, especially in case of more sensitive species.

We hypothesised that in the above-described circumstances the use of quality large planting stock might bring the chance of a solution. An important advantage of large planting stock on frost-exposed sites might rest in the fact that the terminal buds of the saplings could already be above the most extreme ground-frost layer and the level of competing weed (Schmidt-Vogt, 1975; Dušek, 1980). Since the naturally acidic and poor soils in the area of interest have been further acidified and impoverished by pollutants (Lomský *et al.*, 2011), the nutritional regime of new plantations may be a relevant consideration if the replanting of most extreme sites is planned. This is because fertilizing might enhance the frost resistance (Schmidt-Vogt, 1975). A choice of species to replant the harsh site is also very important. On open patches, where replanting efforts failed, the use of pioneer species preparing the site, improving the soil (Moravčík, 1994; Podrázský *et al.*, 2003) and providing the essential shelter seems important.

To verify our hypotheses, we installed a field experiment with rowan (*Sorbus aucuparia* L.), a typical mountain broadleaved species recommended for stabilisation, restoration or diversification of disturbed mountain forest ecosystems in Central Europe (Emmer *et al.*, 1998; Zerbe and Meiwes, 2000). Rowan was chosen for the experiment for its ability to grow on an open unsheltered site, but also its potential to regenerate under the relatively closed canopy in shade (Raspé *et al.*, 2000). Since rowanberries can be propagated by birds (Raspé *et al.*, 2000) to the surrounding already established spruce stands, the experimental plantation could serve as a centre from which this broadleaved species would colonise the area. The promotion of rowan's survival and growth is desirable not only to sooner achieve the positive effects, which rowan stands have on the site quality (Lettl and Hýsek, 1994; Moravčík, 1994), but also in an effort to establish and ensure the highly palatable rowan (Linder *et al.*, 1997; Motta, 2003; Keidel *et al.*, 2008) within the lifespan of game-proof exclosure protecting it from browsing by hoofed game. Since we wanted to test the large-sized planting stock on a frost exposed site, the experimental plantation was established in one of the most extreme frost-hollows in the Czech Republic (Jůza *et al.*, 2011) that was affected by pollution. Apart from the large-sized transplants, the common-sized planting stock was used to enable comparison of the planting stock sizes.

The aims of our experiment were: (1) to compare the survival rate, growth performance and nutrition of large and common-sized planting stock of rowan on an extreme frost-exposed mountain site and (2) to assess whether fertilizing did have any effect on the experimental plantations.

Material and methods

Site description

The experiment was established in the Jizerka valley (50° 49' 8.557" N, 15° 21' 11.742" E) situated in the Jizera Mts. (Jizerské hory), northern Bohemia close to the border between the Czech Republic and Poland in October 2007. The site of the experiment is situated in a frost hollow at an altitude of 860 m at the foot of a mountain ridge on the southwest facing slope (10%) descending to the Jizerka stream. The bedrock is a biotitic granite, the soil (previously probably mountain humic podsol /sandy-loamy podsol) was detrimentally affected by mechanical scarification and removal of a part of the surface humus classified as mor. The chemical properties of the soil on the site are summarized in Table 1.

The climate in the area of the Jizerka valley belongs to North temperate zone, Köppen-Dfc (sub-arctic region), mean annual precipitation 1,400 mm and mean air temperature 4°C (1961-1990); CHMI in Křeček *et al.* (2010). The temperature extremes on the site were documented by Jůza *et al*. (2011).

Planting stock

Two types of planting stock of rowan (*Sorbus aucuparia* L.) were included in the experiment: (i) experimentally produced bare-rooted saplings, aged three (1 + 1 + 1), ca 131-140 cm tall (mean = 135 cm) with 16-19 mm at basal stem diameter (real mean = 17 mm), root-to-shoot ratio > 0.45, fibrous compact root systems and (ii) containerized peat-pot transplants of common dimension purchased in commercial nursery, height class 26-35 cm (mean = 27 cm) and stipulated minimum basal stem diameter of 4 mm (real mean = 6 mm). Both planting stock types were of identical local genetic origin. The saplings were supported by wooden poles (4 × 4 × 200 cm).

Fertilizing

In May 2009, half of the saplings and peat-pot transplants were treated with 30 g (per tree) of Silvamix MG NPK(Mg) 10-13-6,5-(16) slow-release fertiliser (Ecolab Tld.) based on methylene urea and potassium magnesium phosphate. In more concrete terms, the fertilizer had following chemical composition: total nitrogen (N) 10.0%, methylene urea N 6.0%, ureic N (NH_2) 4.0%, available phosphorus (P_2O_5) 13.0%, P_2O_5 soluble in water 8.0%, soluble potassium (K_2O) 6.5% and magnesium (MgO) 16.0%. Three tablets of fertilizer (each tablet weighted 10 g) were placed ca 20-30 cm (saplings) and 15-25 cm (peat-pot transplants) from the stems. They were applied 5 cm under the surface of soil.

The postponement of fertilization reflected the cost-saving efforts and the principles of nature conservation (the experiment is situated in the 2nd zone of protected landscape area). By the postponement of fertilization, the idle application of fertilizer to trees with no chance of recovery from transplanting (with no chance of growing) on extreme site should be avoided, although the postponed fertilizing usually do not reduce plantation mortality as effectively as that immediately applied.

Table 1. Chemical soil properties (prior to fertilization) from the experimental rowan (*Sorbus aucuparia* L.) plantation in the Jizera Mts. (Czech Republic). Soil was sampled including surface humus after greensward removal, *i.e.* the 0-10 cm horizon consists of the surface humus, while the 11-20 cm horizon contains the uppermost mineral soil

Horizon (cm)		Exchange acidity	pH (H_2O)	pH ($CaCl_2$)	C_{tot}	N_{tot}	S_{tot}	P_{avail}	Al_{ex}	Ca_{ex}	K_{ex}	Mg_{ex}
		(mmol/100 g)	(—)	(—)	(mg/100 mg)		(mg/kg)					
0-10	mean	5.25	4.65	3.73	8.27	0.499	538	2.24	388	374	80	191
	sd	0.53	0.02	0.04	1.98	0.089	104	1.24	51	62	4	46
11-20	mean	4.06	4.59	3.73	2.2	0.129	117	0.85	302	88	11	44
	sd	0.66	0.03	0.04	0.46	0.028	31	0.08	54	26	5	11

sd: standard deviation. ICP Forests' procedures used for the analyses. $BaCl_2$ used as extractant for analyses of extractable elements.

Experimental design

The whole experiment contained 300 saplings and 290 peat-pots transplants and was divided into four plots. Each of these plots consisted of approximately the same number of saplings and peat-pot transplants. Two of these plots were fertilized (2009) and the other two left untreated as control (Fig. 1). The plots were separated by buffer zones that were 50 cm wide. In the plots the saplings and peat-pot transplants were planted in downhill oriented rows. The rows of saplings and rows of transplants alternated and were 1 m apart from each other. Within the rows the saplings and peat-pot transplants were planted at a distance of 1.5 m. This spacing was designed to compensate for any eventual variability of the site.

The experiment design was thus composed of four treatments (combinations of planting stock type and fertilizing regime) represented by control saplings (CS) with 147 trees, fertilized saplings (FS) with 153 trees, control peat-pot transplants (CT) with 141 trees and fertilized peat-pot transplants (FT) with 149 trees. Each treatment included 2 replications (Fig. 1). The small differences in numbers among treatments were caused by ground conditions on a forest site (boulders, erosion rills etc.) and omitting the trees from the data files that could be potentially shaded by neighbouring spruces.

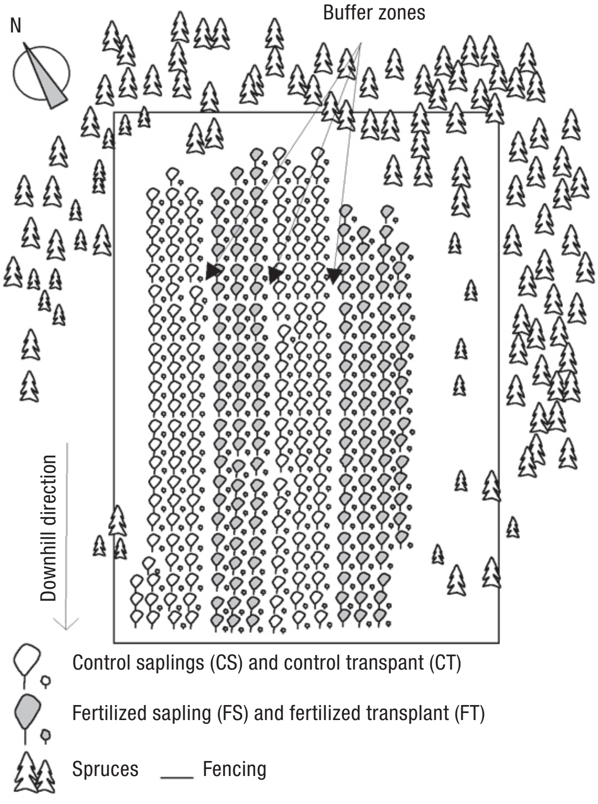

Figure 1. Scheme of the experimental plantation. The experimental plantation consisted of four plots separated by buffer zones. Two of these plots were fertilized and the other two left untreated as control. In each plot the saplings and peat-pot transplants alternated in downhill oriented rows.

Biometric measurements

The article summarises the biometric measurements conducted between autumn 2007 and autumn 2012. The mortality rates were recorded annually and calculated as the percentage of living trees related to the initial numbers of trees planted in 2007. To receive additional information to the mortality rates, the frequency of heavily deformed trees was recorded in 2012. Similarly to mortality rates, the proportion of the heavily deformed trees was related to initial numbers of planted trees. The trees with serious malformations of stem base and stem breakages localised in the lower half of stem were considered as heavily deformed. The tree heights were annually measured to the nearest 1 cm. Except for 2009, the stem base diameters were measured annually since autumn 2008 with an accuracy of ± 1 mm in two perpendicular directions and the mean was used for further calculations.

Heavy frosts (temperatures below –25°C) are not an exception in the locality, coating of ice on the plantations and snow movements not infrequently cause mechanical damage to trees in harder winters. This often results in temporary height reduction of damaged trees or sometimes (after exceptionally hard winters) in reduced mean height of whole treatments. This brought some methodological question of how to interpret height growth. To preserve the continuity between the annual height increment and the development of the real plantation height, the height increment is considered as a difference between two subsequent autumnal measurements of height, meaning height increment can show also negative values.

To filter out or reduce the eventual impact of mechanical damage as well as different mortality rates in particular treatments on tree growth, we decided to evaluate simultaneously the heights, annual height increments and basal stem diameters beside to whole treatments also for the 50% of highest trees in each treatment. This percentage is related to the numbers of planted trees and referred as "top 50%" in further text.

All the above-listed parameters were recorded after the end of growth periods (late August or early September).

Nutritional status

Nutritional status of the plantations was assessed by means of foliar analyses. The sampling was carried in late August or early September before the beginning of the autumnal yellowing. The fully sunned leaves were taken. For each treatment 6-7 composite foliar samples were taken annually in the period from 2009 to 2012. The samples were dried at 70°C until the achievement of constant weight. Afterward the concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) in dry mass (oven-dried at 70°C to a constant weight) were determined in the Tomáš Laboratory (Opočno, Czech Republic). The applied analytic chemical methods were briefly summarised in English by Kuneš *et al.* (2012).

The provisional limits for an assessment of nutritional status of rowan used in our study are summarised in Table 2. These limits were estimated on the basis of literature sources (Binns *et al.*, 1989; Kopinga and Van den Burg, 1995; Raspé *et al.*, 2000; Šrámek *et al.*, 2004) and modified according our experiences with rowan nutrition in the region.

The proportions of nutritional elements to N were evaluated using the limits for broadleaves by Kopinga and Burg (1995). The concentrations of foliar S were confronted with pollution criteria presented by Šrámek *et al.* (2004).

Soil sampling and analyses

To describe the soil conditions on the site (Table 1), the soil was sampled using the soil corer (inside diameter = 7 cm) to a depth of 20 cm in September 2012. The soil cores were taken across the experimental plot from the buffer zones influenced neither by rowan litter nor by fertilizer. The soil cores were split into the 0-10 cm and 10-20 cm parts. The parts were pooled in the corresponding samples. Altogether three samples were formed for each layer of soil (0-10 cm and 10-20 cm, respectively). The chemical analyses were conducted in the Laboratories of Forest and Game Management Research Institute (FGMRI Jíloviště-Strnady) in accord

Table 2. Limits for an assessment of nutritional status of rowan (*Sorbus aucuparia* L.) according to dry-mass concentrations of elements in foliage

Dry-mass concentr.	Deficiency	Low/Possible deficiency	Normal/ optimum	Luxorious supply	Source
N	<18	—	18-25	>25	Šrámek *et al.,* 2004
(g kg^{-1})	<15	15-18	19-22	>22	Kopinga, van den Burg, 1995
	—	<17	>20	—	Binns *et al.,* 1989
	<16	**16-18**	**18-23**	**>23**	**Limits used in this study**
P	<1.3		1.3-3.0	>3.0	Šrámek *et al.* 2004
(g kg^{-1})	<1.0	1.0-1.2	1.3-1.6	>1.6	Kopinga, van den Burg, 1995
	—	<1.6	>1.8	—	Binns *et al.,* 1989
	—	—	2.8		Gillham in Raspe *et al.,* 2000
	<1.1	**1.1-1.3**	**1.3-2.8**	**>2.8**	**Limits used in this study**
K	<5.0	—	5.0-10.0	>10.0	Šrámek *et al.* 2004
(g kg^{-1})	<4.0	4.0-6.0	6.5-14.0	>14.0	Kopinga, van den Burg, 1995
	—	<7.0	>9.0		Binns *et al.,* 1989
	—	—	12		Gillham in Raspe *et al.,* 2000
	<4.0	**4.0-5.5**	**5.5-13**	**>13**	**Limits used in this study**
Ca	<3.0	—	3.0-15.0	>15.0	Šrámek *et al.* 2004
(g kg^{-1})	—	—	—	—	Kopinga, van den Burg, 1995
	—	—	5.0-11.5	—	Gillham in Raspe *et al.,* 2000
	<3.0	**3.0-4.5**	**4.5-13.0**	**>13**	**Limits used in this study**
Mg	<1.5	—	1.5-4.0	>4.0	Šrámek *et al.* 2004
(g kg^{-1})	<0.8	0.8-1.4	1.5-2.2	>2.2	Kopinga, van den Burg, 1995
	<1.2	**1.2-1.5**	**1.5-4.0**	**>4.0**	**Limits used in this study**

with standard methods of ICP Forest d methods of ICP Forest (Cools and De Vos, 2010). For analyses of extractable elements $BaCl_2$ was used as extractant.

Temperature measurements

To assess and discuss the vulnerability of different sizes of planting stock to frost events during growth seasons, the air temperatures were recorded at the following levels: (a) +30 cm, *i.e.* in the zone of terminal buds of common-sized planting stock, (b) +100 cm, *i.e.* in the zone of terminal buds of saplings, (c) +200 cm, *i.e.* in the standardized position for meteorological records. The temperatures were recorded at hourly intervals by a temperature logger situated on an open site in the proximity of the experimental plantation. The records from the periods between 1st May and 30th September of 2011 and 2012 were assessed (the temperature logger was installed and tested in 2010).

Statistical analyses

The mortality rates, proportion of heavily deformed trees and number of hourly records with the temperature below 0°C were assessed by means of a binomial test with subsequent multiple comparisons described *e.g.* by Anděl (1998). The chosen significance level for this procedure was 0.05.

Height, height increment, stem-base diameter and outcomes of chemical analyses of leaves were statistically analyzed using two-way analysis of variance (ANOVA). The main effect of contributions of planting stock type (P) and fertilization regime (F) were determined, as well as the existence of significant interaction effect (PF) between these two independent variables was inspected. To meet the requirements of this parametric approach, the height and height increment data of whole treatments (not those representing top 50%) had to be transformed. The chosen transformation formulae (Seshkin, 2011) were as follows:

$y = \left(\frac{x}{100}\right)^2$ for height, where x stands for height values (cm),

$y = \sqrt{\frac{x}{100} + \frac{1}{2}}$ for height increment, where x stands for height increment values (cm).

As for annual height increment, the most extreme negative values of damaged trees that were not possible to transform were excluded. Except for the outcomes of chemical analyses the statistically processed files of the mensurational characteristics consisted of the data only relating to the trees alive in the autumn of 2012. Data belonging to the trees dead in 2012 were retrospectively excluded.

Results

Mortality and percentage of heavily deformed trees

The statistical analysis did not reveal any significant differences in the overall mortality rates among the compared treatments (CS, FS, CT, FT) during the evaluated period from 2008 to 2012 (Fig. 2a). The overall mortality was relatively low and did not exceed 5% after 5 years since planting of the rowans on the experimental site. There was nonetheless a high percentage of heavily deformed common-sized transplants (CT and FT) due to mechanical damage inflicted on them by snow. On the other hand, in winter 2011/12 the ice formation on terminal leaders caused frequent breakages of the terminal parts of the saplings. Since only the terminal parts of saplings were mostly affected, the damage to saplings was not usually serious, despite it temporarily influenced the mean height in 2012 (see further text). The frequencies of heavily deformed trees in the CS, FS, CT and FT were 16%, 18%, 57%, and 45%, respectively. The saplings showed a significantly lower frequency of heavily deformed individuals than the common-sized peat-pot transplants (Fig. 2b). Fertilizing had no significant effect in this regard.

Height and height growth

The mean whole-treatment height of saplings (CS and FS) was successively increasing up to 2011 (Suppl. Fig. S1). In winter 2011/12, the frequent top breakages of saplings resulted in height reduction that was not fully compensated by the slower height increment in the subsequent vegetation period. Thus the annual height increments of saplings in 2012 showed negative values (Table 3). Nonetheless, despite this height reduction in the last referred year, the periodic height increments (2008-2012) of the CS and FS treatments were 37 and 34 cm, respectively. The whole-treatment height growth of the common-sized transplants (CT and FT) was significantly slower and mo-

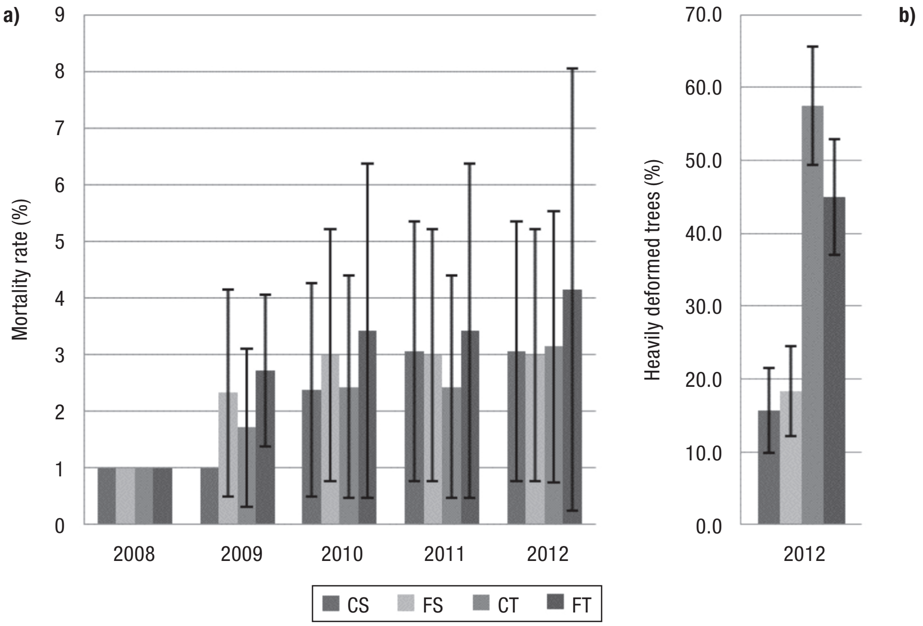

Figure 2. Development of overall mortality rates between 2008 and 2012 (a) and percentage of heavily deformed trees in 2012 (b) including confidence intervals (error bars) for control saplings (CS), fertilized saplings (FS), control transplants (CT) and fertilized transplants (FS), respectively. For overall mortality rates the confidence intervals are depicted since 2009, when the fertilization was applied. No significant differences were proven for mortality, nonetheless, the saplings (CS and FS) showed significantly ($p < 0.05$) lower proportion of heavily deformed trees than transplants (CT and FT).

Table 3. Initial height in autumn 2007 (h2007), annual height increments in the course of the referred period (i2008, i2009, etc.) and periodic height increment over the referred period (i2008-12) of the control saplings (CS), fertilized saplings (FS), control transplants (CT) and fertilized transplants (FT), respectively, calculated for whole treatments and top 50% of trees

Whole treatment	h2007 (cm)	i2008 (cm)	i2009 (cm)	i2010 (cm)	i2011 (cm)	i2012 (cm)	i2008-12 (cm)
Test statistics	$F_{1,561} = 2550$	$F_{1,560} = 33.66$	$F_{1,554} = 27.78$	$F_{1,560} = 166.27$	$F_{1,554} = 45.40$		$F_{1,561} = 25.62$
Significant diff.	P***	P***	P***	P***	P***		P***
CSmean (sd)	133.7 (20.8)	21 (13.1)	6.2 (20.4)	20.4 (14.5)	3.2 (22.9)	–13.9 (37.3)	36.9 (63.5)
FSmean (sd)	136.0 (20.2)	19.9 (13.6)	7.2 (20.7)	22.7 (11.5)	3.3 (16.6)	–19.2 (39.2)	33.9 (61.7)
CTmean (sd)	27.2 (4.0)	14.9 (8.8)	0.6 (12.4)	8.7 (9.6)	–5.0 (12.5)	–4.4 (14.8)	14.9 (22.7)
FTmean (sd)	27.6 (4.2)	15.1 (8.6)	–1.5 (12.5)	9.8 (9.3)	–4.6 (10.4)	–3.9 (14.4)	14.8 (27.8)

Top 50% of trees	h2007 (cm)	i2008 (cm)	i2009 (cm)	i2010 (cm)	i2011 (cm)	i2012 (cm)	i2008–12 (cm)
Test statistics	$F_{1,280} = 4158$	$F_{1,280} = 35.62$	$F_{1,280} = 111.24$ $F_{1,280} = 4.08$	$F_{1,280} = 150.01$	$F_{1,280} = 78.62$	$F_{1,280} = 4.93$	$F_{1,280} = 227.3$
Significant diff.	P***	P***	P***, F*	P***	P***	P*	P***
CSmean (sd)	140.6 (20.5)	25.2 (13.3)	18.3 (9.0)	24.4 (11.3)	12.4 (13.1)	4.1 (15.1)	84.3 (37.0)
FSmean (sd)	143.8 (20.3)	23.2 (12.5)	17.0 (11.0)	27.1 (8.9)	9.7 (9.8)	6.2 (9.3)	83.3 (28.3)
CTmean (sd)	28.3 (4.0)	16.0 (8.8)	5.7 (9.5)	11.9 (8.8)	–0.8 (11.3)	3.3 (10.6)	36.1 (23.9)
FTmean (sd)	28.2 (3.8)	16.3 (8.2)	2.2 (11.4)	12.6 (7.4)	–1.0 (9.7)	1.1 (10.2)	31.2 (19.4)

P (planting stock type) and F (fertilization regime) denote factors responsible for significant differences reported by the two-way ANOVA at a significance level of 0.05 (*), 0.01 (**) and 0.001 (***), respectively.

re often affected by damage or deformations. The periodic height increments (2008-2012) of the CT and FT treatments amounted to 15 cm only (Table 3). The fertilization did not significantly influence the growth of saplings and common-sized transplants, respectively (Table 3).

When the top 50% trees were used for an assessment, the differences were analogous or even more pronounced in favour of saplings. The mean height of the top 50% saplings was not reduced in contrast to whole-treatment mean height after winter 2011/2012 (Fig. S1). The periodic height increments (2008-2012) of the top 50% saplings in the CS and FS were 84 and 83 cm, respectively. The periodic height increments (2008-2012) of the top 50% common-transplants in the CT and FT treatments were again significantly lower than those of saplings and equalled 36 and 31 cm, respectively (Table 3). For the top 50%, trees it was concluded that the fertilization except for 2009 did not significantly influence the growth of saplings and common-sized transplants, respectively (Table 3).

Basal stem diameter

The mean whole-treatment basal stem diameter was slowly growing in all four treatments (Suppl. Fig. S2). Between 2009 and 2012, the saplings (CS and FS) increased their mean basal stem diameter by 3.4 mm. The common-sized transplants (CT and FT) increased their mean basal stem diameter by 2.4 and 2.2 mm, respectively (Table 4). The effect of planting stock size (saplings vs. common-sized transplants) on diameter increment of stem was significant. The fertilization did not significantly influence the growth in basal stem diameter (Table 4).

When the top 50% trees were assessed, we received analogous results for treatment comparison. Between 2009 and 2012, the saplings (CS and FS) increased their mean basal stem diameter by 4.3 and 4.5 mm, respectively. The common-sized transplants (CT and FT) increased their mean basal stem diameter by 3.5 and 3.1 mm, respectively. While the effect of planting stock size on growth in stem base diameter was highly significant, no significant effects of fertilization were recorded in this regard (Table 4).

Nutrition of trees

Fertilization increased foliar N concentration of saplings and common-sized transplants only in the year of application (2009). Later in 2011 the effect of fertilization was converse (Table 5). Planting stock size

Table 4. Basal stem diameter in autumn 2008 (BSD 2008), increment in basal stem diameter over the period between 2009 and 2010 (i2009-2010), annual increments in basal stem diameter in 2011 and 2012 (i2011 and i2012, respectively) and periodic increment in basal stem diameter between 2009 and 2012 (i2009-2012)

Whole treatment	**BSD 2008 (mm)**	**i2009-2010 (mm)**	**i2011 (mm)**	**i2012 (mm)**	**i2009-2012 (mm)**
Test statistics	$F_{1,561} = 3283$	$F_{1,561} = 21.775$		$F_{1,561} = 10.219$	$F_{1,561} = 35.394$
Significant diff.	P***	P***		P**	P***
CS mean (sd)	17 (2.9)	1.5 (1.4)	0.5 (0.8)	1.4 (1.5)	3.4 (2.3)
FS mean (sd)	18 (3.3)	1.5 (1.2)	0.5 (0.8)	1.5 (1.9)	3.4 (2.4)
CT mean (sd)	6 (1.0)	1.0 (1.0)	0.6 (0.9)	1.2 (1.2)	2.4 (1.8)
FT mean (sd)	6 (1.1)	1.1 (1.3)	0.6 (0.8)	1.0 (1.2)	2.2 (2.0)
Top 50% of trees	**BSD 2008 (mm)**	**i2009-2010 (mm)**	**i2011 (mm)**	**i2012 (mm)**	**i2009-2012 (mm)**
Test statistics	$F_{1,280} = 2116$	$F_{1,280} = 12.455$		$F_{1,280} = 4.281$	$F_{1,280} = 17.405$
Significant diff.	P***	P***		P*	P***
CS mean (sd)	18 (2.8)	1.9 (1.4)	0.6 (0.9)	1.7 (1.7)	4.3 (2.5)
FS mean (sd)	19 (3.1)	2.0 (1.2)	0.7 (1.0)	1.9 (1.6)	4.5 (2.2)
CT mean (sd)	6 (1.0)	1.4 (1.1)	0.6 (0.8)	1.6 (1.1)	3.5 (1.5)
FT mean (sd)	6 (1.1)	1.4 (1.5)	0.7 (0.7)	1.4 (1.3)	3.1 (2.1)

P (planting stock type) and F (fertilization regime) denote factors responsible for significant differences reported by the two-way ANOVA at a significance level of 0.05 (*), 0.01 (**) and 0.001 (***), respectively.

Table 5. Mean dry mass concentrations of macronutrients and their sample standard deviations (sd) in foliage of control saplings (CS), fertilized saplings (FS), control transplants (CT) and fertilized transplants (FT) of rowan

Year		N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	S (g kg^{-1})
2009	Test statistics	$F_{1,22} = 11.65$	$F_{1,22} = 15.38$ $F_{1,22} = 6.13$	$F_{1,22} = 6.65$	$F_{1,22} = 26.68$		$F_{1,22} = 10.10$
	Sign. dif.	F**	P***	P*, F*	P***		FP**
	CS mean (sd)	**15.5** (0.59)	1.14 (0.104)	9.7 (1.14)	10.1 (0.70)	2.92 (0.033)	1.2 (0.132)
	FS mean (sd)	**18.4** (2.86)	**1.05** (0.197)	11.1 (0.83)	11.3 (2.38)	3.12 (0.437)	1.43 (0.159)
	CT mean (sd)	16.1 (0.82)	**0.89** (0.106)	9 (1.60)	8.3 (0.71)	3.03 (0.256)	1.42 (0.211)
	FT mean (sd)	17.6 (0.85)	**0.85** (0.144)	9.7 (0.51)	7.8 (0.43)	2.86 (0.101)	1.21 (0.210)
2010	Test statistics				$F_{1,22} = 78.33$		$F_{1,22} = 16.37$
	Sign. dif.				P***		P***
	CS mean (sd)	**14.4** (2.00)	**0.92** (0.234)	10 (1.09)	11.8 (0.73)	4.81 (0.447)	1.58 (0.191)
	FS mean (sd)	**13.5** (0.75)	**0.81** (0.148)	10.7 (1.24)	11.3 (1.01)	4.36 (0.358)	1.48 (0.208)
	CT mean (sd)	**13.4** (0.60)	**0.83** (0.118)	10.8 (1.60)	9 (0.76)	4.81 (0.601)	1.74 (0.194)
	FT mean (sd)	**13.4** (1.05)	**0.86** (0.143)	11.5 (1.25)	8.5 (0.72)	4.6 (0.665)	1.86 (0.087)
2011	Test statistics	$F_{1,23} = 8.14$ $F_{1,23} = 7.69$ $F_{1,23} = 9.66$	$F_{1,23} = 45.67$		$F_{1,23} = 21.78$		
	Sign. dif.	F**	P***, F*, PF**		P***		
	CS mean (sd)	18.2 (0.59)	**0.96** (0.093)	12.7 (1.92)	7.8 (0.81)	3.97 (0.323)	1.39 (0.165)
	FS mean (sd)	17.3 (0.68)	**0.98** (0.093)	13.3 (1.03)	8.2 (0.76)	3.8 (0.161)	1.21 (0.236)
	CT mean (sd)	18.9 (1.50)	1.76 (0.282)	12.7 (2.31)	7 (0.82)	3.76 (0.564)	1.1 (0.213)
	FT mean (sd)	17.9 (–0.45)	1.29 (0.278)	13.2 (0.64)	6.6 (0.37)	3.54 (0.290)	1.25 (0.205)
2012	Test statistics				$F_{1,22} = 49.04$	$F_{1,22} = 5.50$	
	Sign. dif.				P***	F*	
	CS mean (sd)	16.3 (0.91)	**1.03** (0.117)	9.9 (1.39)	10.4 (0.64)	4.41 (0.683)	0.85 (0.090)
	FS mean (sd)	16.3 (0.85)	**0.99** (0.131)	10.8 (0.87)	10.1 (0.79)	3.89 (0.257)	0.75 (0.091)
	CT mean (sd)	16.8 (1.84)	**0.99** (0.056)	10.8 (1.94)	8.5 (0.89)	4.17 (0.878)	0.83 (0.179)
	FT mean (sd)	16.1 (1.21)	**1** (0.102)	11.6 (1.33)	7.7 (0.76)	3.57 (0.508)	0.83 (0.143)

P (planting stock type), F (fertilization regime) and PF (interaction between planting stock type and fertilization regime) denote factors responsible for significant differences reported by the two-way ANOVA at a significance level of 0.05 (*), 0.01 (**) and 0.001 (***), respectively. The figures written in bold represent deficient concentrations of macroelements.

did not prove any significant effect on foliar N concentration. In all treatments the foliar N concentration fluctuated mostly in the zone of low to possibly deficient N supply throughout the evaluated years (see the nutritional limits in Table 2).

Our results suggest that the concentration of foliar P was not positively influenced by fertilization (Table 5). The foliar P might be more dependent on planting stock type than fertilizing, despite the role of planting stock type seeming rather discrepant (compare P concentrations in 2009 and 2011). Except for P concentrations recorded in foliage of common-sized transplants in 2011, the P nutrition of rowans was low and mostly deficient regardless of planting stock type or fertilization.

Fertilization slightly increased the K supply of the treated trees only in the year of application (Table 5). However, the foliar K concentrations indicated sufficient or optimal K supply in all compared treatments throughout the evaluated period 2009-2012.

Foliar Ca concentrations and their statistical analysis suggest that Ca nutrition was influenced by planting stock type and not by applied fertilizing (Table 5). The foliar Ca concentrations indicated sufficient or optimal Ca supply in all compared treatments in the evaluated period 2009-2012.

Except for 2012 neither the planting stock type nor the applied fertilization did significantly influence the foliar Mg concentrations (Table 5). Although in 2012 the fertilization resulted in significantly lower Mg concentration of rowans, the Mg nutrition seemed optimal in all the treatments and evaluated years.

As for foliar S, there was an interaction detected by the two-way ANOVA between the planting stock type and fertilizing in 2009. In 2010 the S concentration in the saplings was significantly lower than in common-sized transplants (Table 5). After 2010 the concentrations of foliar S in all treatments showed a decreasing tendency.

Temperature records

At 30 cm above ground level (terminals of common-sized transplants), there were between the 1st May and 30th September 2011 and 2012 recorded 18 and 20 nights with frost events, respectively. For the same period from May to September, the lowest temperatures in 2011 and 2012 dropped to –11.2°C (4.5.2011) and –8.7°C (18.5.2012), respectively. At 100 cm above ground level (zone of terminals of saplings) between the 1st May and 30th September 2011 and 2012, there were 11 and 9 nights recorded with frost events, respectively. For the same period from May to September, the lowest temperatures in 2011 and 2012 dropped to –8.7°C (4.5.2011) and –6.2°C (18.5.2012), respectively. At 200 cm above ground (reference level) between the 1st May and 30th September 2011 and 2012, there were 3 nights with frost events each year. For the referred period from May to September, the lowest temperatures in 2011 and 2012 dropped to –6.4°C (4.5.2011) and –3.0°C (18.5.2012), respectively. The total numbers of hourly frost records are depicted in Fig. 5 showing significant differences between the compared levels above the ground (+30 cm, +100 cm and +200 cm) in terms of frequency of frost events.

Discussion

Mortality and mechanical damage

A larger planting stock (compared to smaller one) may show increased survival where physical stresses occur, and may also allow planted trees to compete more effectively with other vegetation for resources (Van den Driessche, 1992; Huss, 1993). Although overall mortality in our experiment did not differ among the compared treatments, significant differences in the frequency and character of damage to trees were recorded between assessed types of planting stock (Fig. 2). This could influence the prospects of plantations in the future, since mechanical damage to young forest plantations inflicted by snow and ice are a frequent and serious problem related to forest management in the disturbed Central-European mountains (Šrámek *et al.*, 2008).

Irrespective of treatment (fertilized or unfertilized), the saplings suffered mainly from breakages of terminal parts as result of frost desiccation or heavy snow load and ice coating. This was because the saplings gradually grew taller than the supportive poles and began to protrude from the snow cover in winters. Nonetheless, such damage to rowan saplings was not as serious and was expected, since it was recorded also in older experimental plantations of this planting stock type in the same area though on another species (Kuneš *et al.*, 2011b). Kriegel (2003) referred that, as contrasted to coniferous species, broadleaves such as rowan often suffered from snow and ice coating damage due to the shape of their crowns even after they get above the common level of snow cover. To be noted that saplings suffer from desiccation of terminal leaders quite often and not only on such extreme sites (Huss, 1993). Nonetheless, even frequent top breakages or desiccated terminals, which may result in a temporary decrease in mean plantation height, do not necessarily imply a decrease in establishment success. Possible explanation rests in the fact that the saplings, despite a reduction in height, usually remain above the ground-frost layer and competing vegetation zone (Kuneš *et al.*, 2011b).

The common-sized transplants (CT and FT) mostly suffered from serious stem-base breakages and stem-base deformations. These common-sized transplants, bent or partially broken by snow, suffer entangled in greensward exposed to ground frosts and competing weed throughout the growing periods. Since rowan is a stress-tolerant and resilient species (Raspé *et al.*, 2000), the markedly worse condition of common-sized transplants has not been reflected in the survival rate yet. Nonetheless, due to serious stem deformations, the prospects of common-sized transplants seem much worse than the prospects of saplings. In this regard we agree with Jobidon (2000) and Jobidon *et al.* (2003) who suggested that early survival of plantation should not be used as a criterion for assessing the severity of weed competition.

Note to say that support poles used to stabilize the saplings undoubtedly played a significant role resulting in the absence of serious basal-stem deformations. If the use of saplings is considered in areas of common heavy snowfall, their stabilisation is required (Kuneš *et al.*, 2011a). Therefore, the use of saplings or common-sized transplants should be viewed in the context of the whole technological systems (browsing protection, stabilization etc.). If the common-sized transplants had been supported by the poles, the frequency of the serious basal-stem deformations could have been lower. However, the problem of prolonged exposure to ground frosts and competing vegetation would have not been addressed. This approach would also be economically unjustifiable, since it would mean the necessity of extremely laborious gradual shifting of tapes fastening the trees to support poles, as the trees were growing.

Nutrition and growth

In terms of soil/substratum requirements, rowan is a wide-ranging species. Although it is able to germinate (Zerbe and Meiwes, 2000; Zerbe, 2001) and grow (Emmer *et al.*, 1998) on nutrient poor acidic or acidified sites, the literature reported a potential of rowan to increase its abundance (Hamberg *et al.*, 2009) and growth rate (Gillham in Raspé *et al.,* 2000) on more fertile soils. However, in regard to foliar concentrations of nutritional elements, the effects of fertilizer application were not convincing in our experiment and as for the response in growth, the effects were even not detected. A too low dose of fertilizer (30 g per tree), its formula (a lower percentage of added phosphorus) and nutrient uptake by competing weed might play a role.

Despite a slow-release fertilizer being used, an elevated foliar N was recorded only in the first growth season following its application (Table 5), which probably did not suffice for an initiation of accelerated growth of trees, since otherwise the N concentration was usually low in the leaves of rowan. To be noted that most of soil N on the site (Table 1) was present in the undecomposed organic layers of surface humus (mor) and thus was not available to plants. Moreover, the grasses in the herbaceous layer (*Calamagrostis* community) can be a stiff competitor to trees in uptake of the available fraction of total soil N (Hangs *et al.*, 2003), although they otherwise play an important role in spontaneous biological remedy of the site (Fiala *et al.*, 2005).

Fertilization also failed to increase foliar P (Table 5), which is a deficient element in the nutrition of rowans on the site. The observation of deficient P supply is in accordance with findings in other studies conducted in the area (Špulák, 2009; Koňasová *et al.*, 2012).

The sufficient to luxurious K concentrations in samples' foliage were rather surprising considering the outcomes of studies on other species conducted in the Jizera Mts. (Špulák, 2009; Kuneš *et al.*, 2012). However, these concentration values might be explained with a high K uptake efficiency of rowan (Weihs, 1993; Zerbe and Meiwes, 2000). The sufficient to optimal Ca and Mg concentrations in foliage of rowans of all treatments might reflect the effects of aerial liming practised in the Jizera Mts. in the 1980s.

The concentrations of foliar S (Table 5) indicated an elevated S supply and thus also an increased S contamination of the ecosystem (1-2 g per 1kg of foliar dry mass). However, since 2010 the foliar S concentrations decreased in all treatments and in 2012 the values got below the limits indicating S contamination (concentration of S $<$ 1 g per 1kg of foliar dry mass) according to the classification used in the region (Šrámek *et al.*, 2004). A decreasing trend in foliar S might indicate a successive revitalisation of the area from the S load that was significantly reduced in the 1990s (Fottová and Skořepová, 1998). Nonetheless, it could also be a result of foliar S fluctuation in time.

Regarding ratios of foliar P, K and Mg (their dry mass concentrations) to foliar N, following values can be classified as sufficient: 100 N/5-10 P/25-50 K/5-10 Mg (Kopinga and Van den Burg, 1995). As can be derived from the Table 5, the proportion of P to N remained mostly within the sufficient values in all treatments, despite often being not far from the deficiency limit. The balance between P and N in the foliage was being kept by the fact that both elements (N and P) were limited in nutrition of rowan. Regardless of treatment, the proportions of foliar K and Mg to foliar N were optimal to luxurious. The K/N ratio ranged between 55/100 and 86/100. The Mg/N ratio ranged between 16/100 and 36/100. On the one hand these ratios were given by optimal supply of K and Mg, however, on the other hand they document also limited N supply.

The growth performance showed that the planting stock type of rowans was of significantly greater importance than the applied fertilization. As for a detailed growth comparison between broadleaved bare-rooted saplings with similar dimensions to our rowans and common sized planting stock, we have not found available literature sources. Nonetheless, some implications can be derived from comparison of saplings, semisaplings or large seedlings with common-sized transplants or seedlings, although the studies were conducted mostly on conifers. Schmidt-Vogt and Grüth (1969), Jobidon *et al.* (2003) and Thiffault (2004) reported a greater growth potential and competitive ability of larger planting stock as compared to common stock sizes. According to Van den Driessche (1992), seedlings selected as large in the nursery had significantly greater height than seedlings selected as small throughout the referred period (1984-1990) and absolute size differences increased. A consistent tendency of large planting stock to outperform short planting stock was mentioned also by Newton (1993). To transfer these findings to our situation, this surely does not mean, that only the large-sized material should be used on weeded and frost-exposed mountain sites. There are important also genetic aspects and growth strategies within the species (Leugner and Jurásek, 2012) for which the use of various sizes of planting stock is desirable. However, the saplings might be included to the forestry practice on such sites as a relatively efficient component.

The lack in growth response to fertilization in our experiment probably reflected (among others) the fact that fertilization failed to eliminate the nutritional limitations (N and P) indicated by the foliar analyses.

In the past, areal liming was often used by foresters in the areas affected by acid air pollution including the Jizera Mts. to compensate for acidification, although it meant both positives (*eg.* deacidification of soil, reduction of the mobility of toxic species of Al and heavy metals, increase in Ca and Mg supply, improvement of humus quality) and risks (*eg.* increase in nitrate concentration of the seepage water, reduction of the humus store, mobilization of copper and lead as organic complexes, shallower root systems). All these aspects were in detail documented in literature (Kreutzer, 1995; Podrázský and Ulbrichová, 2003; Kulhavý *et al.*, 2009). At present, when the S deposition has been reduced and the efforts of foresters are aimed more at a diversification of forests and introducing of missing species admixture, the situation might be rather different. The chemical analyses of rowan foliage in our experiment document that the chemical composition of the amendments used for initial fertilizing should more reflect the requirements of the plantation, rather than follow the goal to directly ameliorate a site. In our case more N and P might have been desirable, rather than soil bases in the applied fertilizer. This corresponds to a concept presented by Miller (1981), who suggested that fertilizers should be of benefit to the trees, not the site. From this viewpoint, to provide some initial support for trees, it might be sometimes desirable to apply an N-containing fertilizer even on an N-polluted site, if the N is a deficient element in the nutrition of the species to be supported.

Role of low temperatures

Although rowan is considered a highly viable and frost resistant species (Barclay and Crawford, 1982) able to respond rapidly to mechanical damage (Woodward and Pocock, 1996), we suggest that the extreme temperature events during early growth seasons, as well as snow and ice-coating deformations in winter, might be also important factors influencing growth performance under referred conditions.

The spring frosts in particular seem to be a significant stressing factor for freshly flushed rowans in our experiment. Barclay and Crawford (1984) reported that rowan was able to open buds promptly even at low temperatures during cool springs. This feature of rowan, enabling it possibly to utilise a short growth season (Barclay and Crawford, 1984), seemed to be rather double-edged in the present extreme frost hollow despite the species being autochthonous on the site. Rowan, as a species well adapted to regenerate in grown forests (Zerbe, 2001), was missing the cover of spruce stand and the freshly flushed (sprouted) rowans in the Jizerka locality were subjected to frequent May frost events.

In compliance with general findings (*e.g.* Geiger, 1950), during such nocturnal low temperature events the layer of air closely above the soil surface (+30 cm) often proved to be more extreme than the air in the zone +100 cm in which the saplings have their terminal leaders (Fig. 3). The height of taller saplings probably might at least partly compensate for the missing shelter of an existing grown stand.

Availability and forestry potential of saplings

The saplings (taller than 120 cm) planned and produced for the use in forestry, and tested in this experi-

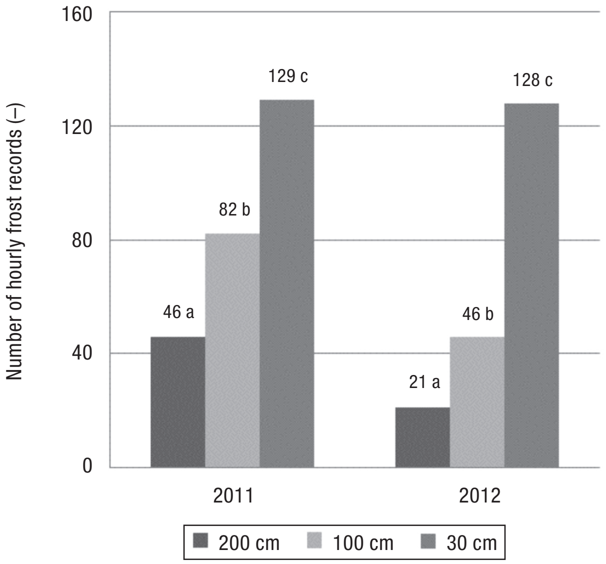

Figure 3. Number of hourly frost records measured in the levels of +30 cm, +100 cm and +200 cm above the ground between 1st May and 30th September of 2011 and 2012, respectively. The levels of +30 cm and +100 cm, respectively, correspond to positions of terminal leaders of common-sized transplants and saplings when rowans were planted. Figures followed by different letters are significantly different from each other at $\alpha = 0.05$.

ment (Suppl. Fig. S3), must fulfil high quality standards (Burda and Nárovcová, 2009; Kuneš *et al.*, 2011a). They, however, have to be also substantially cheaper than a comparable planting stock for amenity purposes. The specially adopted machine technology enables to intensify the production of saplings and thus keeps the production costs low (depending on the species approx. 1-2 EUR per tree). The quality saplings are not intended for common forestry situations. In the extraordinary cases, such as frost-exposed or extremely weeded localities, their use might bring more satisfactory results than use of common-sized planting stock.

Conclusions

Although the overall mortality did not differ among the compared treatments, significant differences were recorded in the frequency and character of damage to planting stock. Irrespective of treatment, the saplings suffered mainly from less serious breakages of terminal parts. The common-sized transplants mostly suffered from stem-base breakages and heavy stem-base deformations.

The planting stock size (saplings *vs.* common sized transplants) significantly influenced the growth performance of rowans. The height growth of saplings was more rapid than that of common-sized transplants. As for growth, neither the saplings nor common sized transplants did significantly respond to initial fertilizing. Also in regard to foliar concentrations of nutritional elements, the effects of applied fertilizer were not persuasive. Foliar N and P concentrations suggest that these two elements might be limiting for growth of rowans regardless of planting stock size. Fertilization failed to elevate N and P nutrition sufficiently and for enough long time.

The extreme temperature events during growth seasons as well as snow and ice-coating deformations might be the decisive factors influencing growth performance of rowans under extraordinarily harsh environmental conditions. On the frost-exposed site the height of taller saplings might at least partly compensate for the shelter of a missing forest stand.

Acknowledgements

Supported by the Ministry of Agriculture of the Czech Republic, Projects NAZV No. QH 92087 and QJ 1220331; Nadace pro záchranu a obnovu Jizerských hor Foundation, Projects No. ZGP 090105 and Czech University of Life Sciences Prague (CULS), Projects No. CIGA 20114314 and CIGA 20124304. The samples of foliage were prepared in the Truba Research Station (Department of Silviculture of the Faculty of Forestry and Wood Sciences, CULS in Prague).

References

Akselsson C, Ardö J, Sverdrup H, 2004. Critical loads of acidity for forest soils and relationship to forest decline in the norhern Czech republic. Environ Monit Assess 98: 363-379.

Anděl J, 1998. Statistické metody (Statistical methods). Matfyzpress, Praha. 274 pp.

Balcar V, Kacálek D, 2008. Growth and health state of silver fir (*Abies alba* Mill.) in the ridge area of the Jizerské hory Mts. J For Sci 54: 509-518.

Balcar V, Kacálek D, Kuneš I, Dušek D, 2011. Effect of soil liming on European beech (*Fagus sylvatica* L.) and sycamore maple (*Acer pseudoplatanus* L.) plantations. Folia Forestalia Polonica, series A 53: 85-92.

Barclay AM, Crawford RMM, 1982. Winter desiccation stress and resting bud viability in relation to high altitude survival in Sorbus aucuparia. Flora: morphologie, geobotanik. Oekophysiologie 172: 21-34.

Barclay AM, Crawford RMM, 1984. Seedling emergence in the rowan (*Sorbus aucuparia*) from an altitudinal gradient. Journal of Ecology 72: 627-636.

Binns WO, Insley H, Gardiner JBHF, 1989. Nutrition of broadleaved amenity trees. Arboricultural research note 50: 1-5.

Burda P, Nárovcová J, 2009. Ověřování technologie pěstování poloodrostků a odrostků v lesních školkách (Testing of the technology for production of large-sized planting stock in forest nurseries). Zprávy lesnického výzkumu 54, 92-98.

Cools N, De Vos B, 2010. Sampling and Analysis of Soil. Manual Part X. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE, ICP Forests, Hamburg. p: 208.

Dušek V, 1980. Současný stav a perspektivy aplikace silného sadebního materiálu (přehled literatury) [Present state and prospects of using the large-sized planting stock (literature review)]. Zprávy lesnického výzkumu 25: 1-5.

Emmer IM, Fanta J, Kobus AT, Kooijman A, Sevink J, 1998. Reversing borealization as a means to restore biodiversity in Central-European mountain forests? An example from the Krkonoše Mountains, Czech Republic. Biodivers Conserv 7: 229-247.

Fiala K, Tůma I, Holub P, Jandák J, 2005. The role of Calamagrostis communities in preventing soil acidification and base cation losses in a deforested mountain area affected by acid deposition. Plant Soil 268: 35-49.

Filipiak M, Ufnalski K, 2004. Growth Reaction of European Silver Fir (*Abies alba* Mill.) Associated with Air Quality Improvement in the Sudeten Mountains. Polish Journal of Environmental Studies 13: 267-273.

Fottová D, 2003. Trends in sulphur and nitrogen deposition fluxes in the GEOMON network, Czech Republic, between 1994 and 2000. Water Air Soil Pollut 150: 73-87.

Fottová D, Skořepová I, 1998. Changes in mass element fluxes and their importance for critical loads: geomon network, Czech Republic. Water Air Soil Pollut 105: 365-376.

Geiger R, 1950. The climate near the ground. Harward University Press, Cambridge. 482 pp.

Hamberg L, Malmivaara-Lämsä ML, Susanna, Kotze DJ, 2009. The effects of soil fertility on the abundance of rowan (*Sorbus aucuparia* L.) in urban forests. Plant Ecol 209: 21-32.

Hangs RD, Knight JD, Van Rees KCJ, 2003. Nitrogen uptake characteristics for roots of conifer seedlings and common boreal forest competitor species. Can J For Res 33: 156-163.

Hrkal Z, Fottová D, Rosendorf P, 2009. The relationship between quality of ground waters and forest cover in regions affected by high levels of acid atmospheric deposition – A case study of the Krušné hory Mts., Czech Republic. Polish Journal of Environmental Studies 18: 995-1004.

Hrkal Z, Prchalová H, Fottová D, 2006. Trends in impact of acidification on groundwater bodies in the Czech Republic; An estimation of atmospheric deposition at the horizon 2015. Journal of Atmospheric Chemistry 53: 1-12.

Huss VJ, 1993. Waldbau vor neuen Herausforderungen bei Waldverjiingung und Jungbestandspflege Forstwiss Cantralbl 112: 278-286.

Jobidon R, 2000. Density-dependent effects of northern hardwood competition on selected environmental resources and young white spruce (*Picea glauca*) plantation growth, mineral nutrition, and stand structural development – A 5-year study. For Ecol Manag 130: 77-97.

Jobidon RJ, Roy V, Cyr G, 2003. Net effect of competing vegetation on selected environmental conditions and performance of four spruce seedling stock sizes after eight years in Québec (Canada). Ann For Sci 60: 691-699.

Jůza P, Starostová M, Sklenář K, 2011. Naměřená minima teploty vzduchu na vybraných horských stanicích v Čechách (Minimal air temperatures measured at some mountain stations in Bohemia). Meteorologické zprávy 64: 10-17.

Keidel S, Meyer P, Bartsch N, 2008. Regeneration eines naturnahen Fichtenwaldökosystems im Harz nach großflächiger Störung. Forstarchiv 79: 178-196.

Koňasová T, Kuneš I, Baláš M, Millerová K, Balcar V, Špulák O *et al., 2*012. Influence of limestone and amphibolite application on growth of Norway spruce plantation under harsh mountain conditions. J For Sci 58: 492-502.

Kopinga J, Van den Burg J, 1995. Using soil and foliar analysis to diagnose the nutritional status of urban trees. J Arboric 21: 17-24.

Kreutzer K, 1995. Effects of forest liming on soil processes. Plant Soil 168-169: 447-470.

Křeček J, Hořická Z, 2001. Degradation and recovery of mountain watersheds: the Jizera Mountains, Czech Republic. Unasylva 52: 43-49.

Křeček J, Hořická Z, 2006. Forests, air pollution and water quality: influencing health in the headwaters of Central Europe's "Black Triangle". Unasylva 57: 46-49.

Křeček J, Hořická J, Hořická Z, 2010. Ellenberg's indicator in water resources control: The Jizera Mountains, Czech Republic. Ecol Eng 36: 1112-1117.

Kriegel H, 2003. Ovlivnění vývoje kultur v horách sněhem (Influence of snow layer on growth of plantings in mountains). Zprávy lesnického výzkumu 48: 25-29.

Kulhavý J, Marková I, Drapelová I, Truparová S, 2009. The effect of liming on the mineral nutrition of the mountain Norway spruce (*Picea abies* L.) forest. J For Sci 55: 1-8.

Kuneš I, 2003. Prosperity of spruce plantation after application of dolomitic limestone powder. J For Sci 49: 220-228.

Kuneš I, Baláš M, Burda P, Millerová K, 2011a. Reintroducing broadleaves to mountain coniferous stands under harsh environmental conditions. Bulletin of Szent István Univerzity: 123-134.

Kuneš I, Baláš M, Koňasová T, Zahradník D, Balcar V, Špulák O *et al., 2*012. Cultivation of speckled alder under harsh mountain conditions. J For Sci 58: 234-244.

Kuneš I, Baláš M, Millerová K, Balcar V, 2011b. Vnášení listnaté příměsi a jedle do jehličnatých porostů Jizerských hor (uplatněná certifikovaná metodika č 231921/2011-MZE-16222/M28) [Introducing of broad-leaved and fir admixture into coniferous stands in the Jizera Mts. (Forestry guide No, 231921/2011-MZE-16222/M28)]. ČZU a VÚLHM, Praha a Jíloviště-Strnady. 44 pp.

Lettl A, Hýsek J. 1994. Soil microflora in an area where spruce (*Picea abies*) was killed by SO_2 emissions and was succeeded by birch (*Betula pendula*) and mountain ash (*Sorbus aucuparia*). Ecol Eng 3: 27-37.

Leugner J, Jurásek A, 2012. Hodnocení morfologických parametrů horských populací smrku ztepilého s různou růstovou strategií (Assessment of morphological parameters of Norway spruce mountain populations with different growth strategy). Zprávy lesnického výzkumu 57: 195-201.

Linder P, Elfving B, Zackrisson O, 1997. Stand structure and successional trends in virgin boreal forest reserves in Sweden. For Ecol Manag 98: 17-33.

Lomský B, Šrámek V, Novotný R, 2011. Changes in the air pollution load in the Jizera Mts.: effects on the health status and mineral nutrition of the young Norway spruce stands. Eur J For Res 131: 757-771.

Mazurski KR, 1999. Environmental problems in the Sudetes, Poland. GeoJournal 46: 271-277.

Miller HG, 1981. Forest fertilization: some guiding concepts. Forestry 54: 157-167.

Moravčík P, 1994. Development of new forest stands after a large scale forest decline in the Krušné hory Mountains. Ecol Eng 3: 57-69.

Motta R, 2003. Ungulate impact on rowan (*Sorbus aucuparia* L.) and Norway spruce [*Picea abies* (L.) Karst.] height structure in mountain forests in the eastern Italian Alps. For Ecol Manag 181: 139-150.

Newton M, 1993. Tall planting stock for enhanced growth and domination of brush in the Douglas-fir region. New Forests 7: 107-121.

Podrázský V, Remeš J, Ulbrichová I, 2003. Biological and chemical amelioration effects on the localities degraded by bulldozer site preparation in the Ore Mts. – Czech Republic. J For Sci 49: 141-147.

Podrázský V, Ulbrichová I, 2003. Surface liming of immission clear-cuts: benefits and risks. Ekol Bratislava 22: 277-283.

Pyšek P. 1994. Effect of soil characteristics on succession in sites reclaimed after acid rain deforestation. Ecol Eng 3: 39-47.

Raspé O, Findlay C, Jacquemart A-L, 2000. Biological flora of the British Isles No, 214 List Br Vasc Pl, 232, 1 Sorbus aucuparia L. Journal of Ecology 88: 910-930.

Seshkin DJ, 2011. Handbook of parametric and nonparametric statistical procedures. CRC Press, Boca Raton. 1886 pp.

Schmidt-Vogt H, 1975. Morphologische und physiologische Eigenschaften von Pflanzen. Forstwiss Cantralbl 94: 19-28.

Schmidt-Vogt H, Gırth P, 1969. Eigenschaften von Forstpflanzen und Kulturerfolg. I. Mitteilung: Anpflanzungsversuche mit Fichten- und Kiefernpflanzen verschiedener Größen und Durchmesser. Allgemeine Forst- und Jagdzeitung 140: 132-142.

Špulák O, 2009. Produkční potenciál mladého porostu smrku pichlavého a akumulace živin v nadzemní biomase. (Production potential of blue spruce young stand and nutrient accumulation in the aboveground biomass). Zprávy lesnického výzkumu 54: 85-91.

Šrámek V, Novotný R, Lomský B, Maxa M, Neuman L, Fadrhonsová V, 2004. Změny obsahů prvků v porostech smrku, buku, jeřábu a břízy v průběhu roku (závěrečná zpráva grantu) (Final Report of a Grant Project). VÚLHM, Jíloviště-Strnady.

Šrámek V, Slodičák M, Lomský B, Balcar V, Kulhavý J, Hadaš P *et al., 2*008. The ore mountains: will successive recovery of forests from lethal disease be successful? Mountain Research and Development 28: 216-221.

Thiffault N, 2004. Stock type in intensive silviculture. The Forestry Chronicle 80: 463-468.

Van den Driessche R, 1992. Absolute and relative growth of Douglas-fir seedlings of different sizes. Tree Physiol 10: 141-152.

Weihs U, 1993. Walderneuerung auf Problemstandorten der Harzhochlagen - ein Baumartenanbau- und Düngungsversuch. Berichte des Forschungszentrums Waldökosysteme der Universität Göttingen, Reihe A Bd. 12: 1-330.

Woodward S, Pocock S, 1996. Formation of the ligno-suberized barrier zone and wound periderm in four species of European broad-leaved trees. European Journal of Forest Pathology 26: 97-105.

Zerbe S, 2001. On the ecology of *Sorbus aucuparia* (*Rosaceae*) with special regard to germination, establishment and growth. Polish botanical journal 46: 220-239.

Zerbe S, Meiwes KJ, 2000. Zum Einflufluss von Weichlaubhölzern auf Vegetation und Auflagehumus von Fichtenforsten - Untersuchungen in einem zwei Jahrzehnte alten Birken-Ebereschen-Vorwald im Hoch-Solling Forstwiss Cantralbl 119: 1-19.