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Effect of mineral eco-fertilizer on growth and mortality of young afforestations

Auswirkung von mineralischen ökologischen Düngungsmitteln auf Wachstum und Mortalität junger Aufforstungen

Jan Cukor [1], Zdeněk Vacek [1], Rostislav Linda [1], Jiří Remeš [1*], Lukáš Bílek [1], Ram P. Sharma [1], Martin Baláš [1], Ivo Kupka [1]

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Schlüsselbegriffe: *landwirtschaftliches Land; Düngung; Sämlinge; Alginit; organisches Sediment; Zentraleuropa*

Abstract

Afforestation of the marginal agricultural lands located on unfavourable climatic and site conditions often results in a substantial failure. This problem may be mitigated through site improvement, e.g. fertilization by fossil materials such as Alginite. The objective of this study was to evaluate the effect of Alginite on the height growth, mortality, and nutrient contents in the assimilation apparatus of the seedlings of Scots pine (*Pinus sylvestris* L.), English oak (*Quercus robur* L.), red oak (*Quercus rubra* L.) and Norway maple (*Acer platanoides* L.) on former agricultural land with an unfa-

[1] Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague, Kamýcká 129, 169 51 Prague 6 – Suchdol, Czech Republic,,
*Corresponding author: Jiří Remeš (remesj@email.cz)

vourable hydrophysical regime. A research locality (9600 m^2), which is located in the central part of the Czech Republic, was divided to 27 sub-plots, and then these sub-plots were afforested using the central hole planting method with a spacing of 1×1 m. Scots pine and English oak were planted on the monospecific basis, and English oak, red oak and Norway maple were planted in mixture. Three different treatments were applied on each sub-plots: no application of Alginite (control, variant A), application with dose of 0.5 kg per plant (variant B), application with dose of 1.5 kg per plant (variant C). Four hundred seedlings were planted on each sub-plot and each variant with a particular tree species had three replications. Growth related parameters and other characteristics of each plant were measured every consecutive year after plantation (on spring 2013) to 2015. The results showed that there was a significantly higher height growth rate of broad-leaved species, which were treated with a variant B. However, reaction to the application of Alginite by individual species was substantially different and the effect of fertilization was remarkably higher for Maple compared to that for English oak. Fertilization by Alginite had a remarkably positive effect on afforestation of the marginal and abandoned agricultural lands. Fertilization also significantly reduced the seedling mortality rate in the first year after planting.

Zusammenfassung

Aufforstung von landwirtschaftlichen Flächen in Gebieten mit ungünstigen klimatischen und standörtlichen Bedingungen versagen häufig. Dieses Schlüsselproblem kann teilweise durch Düngung gemildert werden, z.B. mit einem der fossilen Düngungsmitteln wie Alginit. Diese Studie setzt sich zum Ziel, die Auswirkung vom Alginit auf Höhenzuwachs, Mortalität und Nährstoffgehalt im Assimilationsapparat der Sämlinge der Waldkiefer (*Pinus sylvestris* L.), Stieleiche (*Quercus robur* L.), Roteiche (*Quercus rubra* L.) und des Spitzahorns (*Acer platanoides* L.) auszuwerten, und zwar auf einem ehemaligen landwirtschaftlichen Land mit einem ungünstigen hydrophysischen Regime. Das Forschungsgebiet (9 600 m^2) befindet sich im zentralen Teil der Tschechischen Republik und besteht aus 27 Teilflächen, die durch Lochpflanzung mit Abstand 1×1 aufgeforstet wurden. Waldkiefern und Stieleichen wurden in reinen Beständen gepflanzt. Stieleiche, Roteiche und Spitzahorn wurden in Mischung ausgepflanzt. Alginit wurde in drei Varianten aufgewendet: Kontrollvarieante A ohne Zusatz, Variante B mit einer Dosis von 0,5 kg pro Pflanze und C-Variante mit 1,5 kg pro Pflanze. Vierhundert Individuen wurden auf jeder Teilfläche gepflanzt, jede Variante mit bestimmter Baumart hat 3 Wiederholungen. Die Wachstumsparameter und andere Merkmale der einzelnen Bäume wurden jedes Jahr von der Aufforstung (im Frühjahr 2013) bis 2015 gemessen. Die Ergebnisse zeigen, dass das signifikant höhere Höhenwachstum der Sämlinge der Laubbaumarten in der Variante B lag. Jedoch die Reaktion der einzelnen Baumarten war verschieden, wobei Anwendung von Alginit besonders bei Ahorn im Vergleich zu Stieleiche bemerkenswert war. Die Düngung mit Alginite hatte einen positiven Einfluss auf die Entwicklung der Landaufforstung; eine positive Auswirkung auf die Mortalität von Sämlingen im ersten Jahr nach der Pflanzung wurde auch bestätigt.

1. Introduction and problem analysis

Afforestation of the marginal and abandoned agricultural lands has been an issue in the Central Europe for last two centuries (Špulák and Kacálek 2011). However, an opposite trend prevailed in the earlier times, i.e., deforestation was mainly carried out for firewood, construction materials, but also the lands suitable for agricultural usages (Williams 2000; Kaplan et al. 2009). The first written record of agricultural land afforestation in Bohemia came from the late 16^{th} century in the game preserves located nearby Prague and Karlovy Vary (Kacálek and Bartoš 2002). Another source dates back to 1589, which describes a new forest planting nearby Hvězda game park located two miles away from Prague (Špulák 2006). However, afforestation of the largest abandoned agricultural land began after the World War II (Kacálek and Bartoš 2002), especially in the border regions after taking over the Sudeten land (Špulák and Kacálek 2011). About 6,000 ha of the barren land was afforested every year in 1960s and later on, afforestation was carried out at a rate of 1,000 ha per year (Černý et al. 1995). Norway spruce (*Picea abies* (L.) Karst.) was the most common species in the newly established forests with afforestation, but also there were other tree species included, such as European larch (*Larix decidua* Mill.), black alder (*Alnus glutinosa* (L.) Gaertn.), Scots pine (*Pinus sylvestris* L.) and European ash (*Fraxinus excelsior* L.) (Hatlapatková et al. 2006; Šindelář and Frýdl 2006; Vacek et al. 2015, 2016). Favourable effects of broadleaved tree species compared to Norway spruce were often documented (Podrázský and Procházka 2009a, 2009b).

On the global perspective, there has been a large potential of afforestation of the marginal agricultural and degraded lands. Campbell et al. (2008) reported that about 385–472 million ha of the abandoned agricultural land is suitable for establishing the plantation of fast-growing tree species. In the Europe, the future land-use scenarios predict a substantial decrease of agricultural land, and one of the reasons for this is an afforestation (Rounsevell et al. 2006; Stoate et al. 2009; Ruskule et al. 2016). The estimated area of afforestation of the marginal and abandoned agriculture land is about 12-16 million ha (FAO 2008; Campbell et al. 2008). There is also a large area of non-forested land suitable for afforestation in the Czech Republic. A precise estimate depends largely on the criteria used, e.g. Podrázský and Štěpaník (2002) have reported that an area of 50,000 - 500,000 ha may be used for afforestation, and therefore it needs to pay attention to this issue (Vopravil et al. 2015).

The most problematic phase of afforestation, particularly in the extremely harsh climatic and site conditions, is undoubtedly the phase of planting. The initial growth and establishment of plantations determine, to a great extent, the growth and development of individual trees in the latter stages (Kupka et al. 2015). Any failure in afforestation and reforestation is often caused by adverse soil conditions, and site quality can also be problematic in terms of anthropogenically altered environmental conditions, and specific microsite conditions (Schönenberger 2001; Colak 2003; Borůvka et al. 2005; Fuerst et al. 2007; Balcar et al. 2012). However, tree species have certain mechanisms that allow successful growth and development even under the adverse site conditions (Vacek and Hejcman 2012; Vacek et al. 2012; Králíček et al. 2017). Besides the production aspects, the improvement of soil through increasing infiltration and retention capacity for water, accumulation of surface humus and considerable pedochemical changes have to be expected (Holubík et al. 2014; Podrázský et al. 2009, 2015, 2016).

Various measures could be designed to facilitate reforestation/afforestation in forestry practices, which were categorized into the groups of chemical and biological reclamation or site improvement measures (Podrázský 1994; Podrázský et al. 2004; Bergh et al. 2008; Kuneš et al. 2011; Hedwall et al. 2013; Peragón et al. 2015). The ameliorative intervention may involve the application of lime or basic rocks (Kuneš et al. 2009; Pabian et al. 2012), or special slowly soluble fertilizers (Kuneš et al. 2004). Also, numerous deciduous tree species have favourable silvicultural characteristics that support their growth in the unfavourable site conditions, especially on the mountain regions (Augusto et al. 2002; Podrázský et al. 2004; Cukor et al. 2017).

This study focuses mainly on afforestation of the non-forested land in the area, which is favourable for various tree species. The non-forested lands, which represent the limits for successful afforestation, are characterized with a higher temperature and low precipitation in the growing season (Tužinský et al. 2015). One of the important factors ensuring successful afforestation and good survival rate of seedlings is available soil moisture on the upper horizon of the soil profile. Lack of moisture in the soil substantially affects the root system, which is more sensitive than the aboveground part of the plant. This problem may be partially mitigated by supplements of the fossil minerals such as Alginite (Kupka et al. 2015), which, *inter alia*, can enhance water uptake in the root area of seedlings.

The Alginite is an organic sediment belonging to the oil shale, which arose 3-4 million years ago during volcanic changes (Kulich et al. 2001; Kadar et al. 2015). This gray to dark gray rock is rich in organic matter. Alginite contains 5 to 50%, even 90% of organic matter (Szabó 2004). It is created by aquatic algae, and therefore has a high proportion of mineral elements such as phosphorus, potassium, calcium and magnesium (Gömöryová et al. 2009). Application of Alginite as one of the eco-fertilizers in afforestation was described by Vass et al. (1997, 1998), and its effect on seedlings in the first year after afforestation of the marginal agricultural land has also been described by Tužinský et al. (2015) and Kupka et al. (2015).

The hypothesis of this study was that fertilization by Alginite might have a significant positive effect on the growth parameters of seedlings, especially in the first year after they are planted. The objectives of this study were to (1) determine the effect of Alginite on the survival rate (mortality) of seedlings of the selected four tree species; (2) compare the height increment of seedlings for different variants of Alginite application; and (3) evaluate the nutrient contents in the assimilation apparatus on three year's growth of seedlings on the control sample plots, and the plots with application of two different amounts of Alginite.

2. Materials and Methods

2.1. Study area

The effect of Alginite as an eco-fertilizer substance for site improvement at the afforestation of non-forested land was evaluated on the relatively dry area nearby Hovorčovice village, north of Prague (Natural Forest Area Polabí 17), Czech Republic (GPS: N 50 ° 14.4 'E 14 ° 28.12'). Location and design of research sample plot are shown in Figure 1. This area is called "U Hnojiště", and it is a former agricultural/arable land in a warm, moderately dry area with the average annual temperature of 8 - 9° C. The average annual precipitation on the study site varies from 500 to 600 mm and dry vegetation period varies from 20 to 30%. A territory of the study site is characterized by warm dry summer and cool dry winter with a narrow annual temperature range (Köppen 1936), where average length of the growing season is about 168 days. The soil is identified as Chernozem, 30 to 70 cm deep, rocked, eroded flat terrain (forested arable land).

A research sample plot of size 9600 m^2 was divided into equal size of the 23 larger sub-plots (each with 20 m × 20 m dimensions) and 4 smaller sub-plots (each with 10 m × 10 m dimensions). All 27 sub-plots were afforested in the spring 2013 using the central hole planting method with a spacing of 1 m × 1 m. Tree species used for planting are: Scots pine (*Pinus sylvestris* L.), English oak (*Quercus robur* L.) in a separate row planting and English oak, Red oak (*Quercus rubra* L.) and Norway maple (*Acer platanoides* L.) in a line mixture planting. Besides on the control sub-plots, i.e. without application of Alginite (control. variant A), Alginite with doses of 0.5 kg (variant B) and 1.5 kg of Alginite (variant C) per seedling were applied. A full doze of fertilizer was applied on the bottom of a hole prepared nearby for each seedling. Each of the larger and smaller sub-plots was planted with 400 and 100 seedlings, respectively.

A Czech company NOZA s. r. o. (Huťská 229, 272 01 Kladno) supplies the Alginite, which was used in this study, and one kilogram of this mineral contained: Ca 15-528 mg, Mg 1841 mg, P 42.9 mg, K 196 mg, and 0.207% N of a total content.

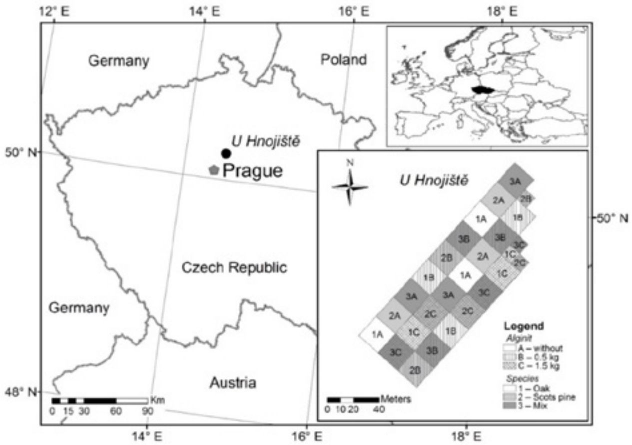

Fig. 1: Location of research sample plot "U Hnojiště" and sub-plots with application of different variants of Alginite

2.2. Data collection

Height of each seedling was measured in 2013, 2014 and 2015, and average height growth rate was calculated. Annual mortality was also observed. The assimilation apparatus samples were taken in each sub-plot by the random selection with the random numbers (generated in RNG, Excel) assigned to the 50 individuals, and selected from these individuals of deciduous tree species in August and conifers in October in 2015. Three bulk samples were taken on each sub-plot for each tree species and for each variant.

Chemical analysis of the assimilation apparatus was performed in the laboratory of Tomáš in VÚLHM Opočno using the standard methodology (Zbíral 2001). The concentrations of macro-elements (N, P, K, Ca, Mg) of dry matter of the assimilation apparatus were compared using the classification limits reported in Bergmann (1993).

2.3. Data analysis

Height increment data obtained from 2013 to 2015 were analysed to evaluate the effect of the application of different Alginite variants (control, variant B, variant C) using the Statistica 12 software (StatSoft, Tulsa). The Kruskal-Wallis test was performed with the relevant multiple comparisons. Mortality was expressed in the percentage of Alginite applications by tree species and years using the method of multiple comparisons of *P* parameters of the binomial distribution (Anděl 1998). The results are presented as homogenous groups. The hypotheses were tested using 5% significance level (alpha=0.05). In order to reduce or avoid the boarder effects (edge effects) potentially caused by treatments of neighbouring seedlings, all seedlings located nearby plot-edge were excluded. We excluded 76 seedlings from each of the larger sub-plot and 36 seedlings from each of the smaller sub-plot.

An unconstrained principal component analysis (PCA) was applied in the CANOCO for Windows 4.5 program (Ter Braak and Šmilauer 2002) in order to analyse the relationships among the number of seedlings and mean height of seedling, mortality, mean height increment, nutrient contents in the assimilation apparatus, tree species, and variants of Alginite application. Data were centered and standardized during the analysis. The results from PCA were visualized in the form of the ordination diagram produced by the CanoDraw program (Ter Braak and Šmilauer 2002).

3. Results

3.1. Seedling mortality

Seedling mortality of Scots pine, English oak, red oak and Norway maple in the years 2013-2015 showed substantial differences in response to the application of Alginite (Table 1). Alginite application showed the largest difference in the first year of planting (i.e. autumn 2013). Even though positive effect of both smaller and larger doses of Alginite was observed in Scots pine, but difference was not significant ($p>0.05$). Except red oak, which responded to only high amount of Alginite application, other deciduous species showed positive responses to both B and C variants, and all these responses were highly significant ($p<0.05$). However, in the first year after planting, it was also found that responses to the application of Alginite on both conifer and deciduous spices were negative. The mortality rate significantly decreased in 2015 compared to that of the previous years. A response to the application of Alginite was also positive in Scots pine, which is equivalent to that in the deciduous species.

Table 1: Mortality of particular species after Alginite application in a period between 2013 and 2015

Species	Variant	Number of trees planted - spring 2013	Fall 2013 (%)	Fall 2014 (%)	Fall 2015 (%)
Pine	A	972	21.6 a	11.8 a	1.0 a
Pine	B	729	17.4 a	**30.4 b**	0.9 a
Pine	C	972	21.4 a	**38.7 c**	0.8 a
Oak	A	972	5.6 a	1.6 a	2.1 a
Oak	B	972	**2.4 b**	**13.3 b**	4.0 a
Oak	C	727	**2.6 b**	**5.2 c**	**7.5 b**
Oak in mixture	A	276	22.5 a	1.9 a	4.3 a
Oak in mixture	B	303	**6.9 b**	**9.6 b**	1.2 a
Oak in mixture	C	261	**2.7 b**	**6.3 ab**	4.2 a
Maple	A	377	8.0 a	0.6 a	1.2 a
Maple	B	342	**2.1 b**	1.2 a	0.3 a
Maple	C	243	**0.8 b**	0.8 a	0.4 a
Red oak	A	320	35.0 a	36.5 a	2.3 a
Red oak	B	328	27.7 a	28.7 a	0.6 a
Red oak	C	227	**6.6 b**	**61.3 b**	7.3 b

Note: Significant differences between Alginite variants are indicated with different indices

3.2. Height increment

Table 2 shows an overview of an evaluation of the growth of seedlings based on the application of different variants of Alginite. The effect of Alginite was different for different species. In the first year of planting, there was a positive response for Scots pine treated with C variant, oak also responded positively for variants B and C but only in the monoculture, and these all responses were significant ($p<0.05$). The effects of the application of Alginite on other species were positive, but they were not significant ($p>0.05$). The negative response, which is also significant, was found only for maple treated with variant C. The reaction of all tree species were mostly positive also in the second year after planting. Different behaviour was observed on Scots pine threated with variant B, which showed a lower height increment compared to that of variant A, while variant C showed a large positive effect on the height increment. There was an unclear response pattern observed for oak in the monoculture, whereas height increment was slightly higher in the mixture. A significantly large height increment was observed for maple treated with variant B or C, and red oak responded with a higher height increment for variant B. The effect of Alginite was positive only for red oak treated by variant B or C in 2015. A slightly higher height increment was found for oak treated with variant B, but application of a higher amount of Alginite had a negative effect. Maple also showed an unclear response pattern on the height increment for each of the three variants. However, there was a slightly different situation for Scots pine, in which application of Alginite showed a negative effect, but both variants B and C showed significantly lower height increments than those for the control treatment (control, Alginite A).

Table 2: Height increment of particular tree species after Alginite application in a period between 2013 and 2015

Species	Variant	Number of plants	Height 2013	P. value	Mean incr 13	P. value	Mean incr 14	P. value	Mean incr 15	P. value
Pine	A	972	25.9 a		13.3 a		23.2 a		40.8 a	
Pine	B	729	**27.1 b**	<0.001	13.2 a	<0.001	**21.6 b**	<0.001	**35.4 b**	<0.001
Pine	C	972	**28.6 c**		**15.2 b**		**24.3 c**		**37.7 c**	
Oak	A	972	25.0 a		7.9 a		14.2 a		10.7 a	
Oak	B	972	25.5 a	<0.001	**9.9 b**	<0.001	14.3 a	0.49	11.7 a	<0.001
Oak	C	727	**26.5 b**		**9.5 b**		14.0 a		**8.8 b**	
Oak in mixture	A	276	25.0 a		9.1 a		14.4 a		11.0 a	
Oak in mixture	B	303	25.2 a	0.856	**8.2 b**	<0.001	15.6 a	0.87	12.5 a	<0.001
Oak in mixture	C	261	25.4 a		**8.0 b**		15.0 a		**8.8 b**	
Maple	A	377	50.7 a		12.4 a		33.1 a		29.1 a	
Maple	B	342	**54.1 b**	<0.001	13.2 a	<0.001	**44.8 b**	0.03	25.4 a	0.06
Maple	C	243	**54.4 b**		**11.0 b**		**42.1 ab**		29.3 a	
Red oak	A	320	59.7 a		13.6 a		8.3 a		9.8 a	
Red oak	B	328	60.1 a	<0.001	12.9 a	0.32	9.8 a	0.37	**13.8 b**	0.07
Red oak	C	227	**67.2 b**		11.8 a		6.7 a		**13.0 b**	

Note: Significant differences between Alginite variants are indicated with different indices; SE: standard error

A general evaluation of the effects of Alginite on the height increments for a period between 2013 and 2015 is presented in figure 2. Generally, height increment is positive for all broad-leaved species treated with variant B, and significant difference was found in the height growth for maple and oak planted in the monoculture. A negative effect was observed for Scots pine treated with variant B and for oak planted in mixture and treated with variant C.

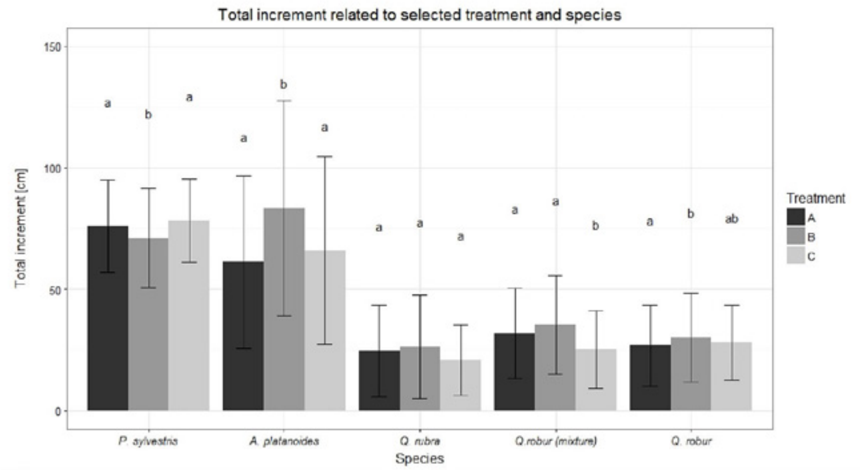

Fig. 2: Total height increment of seedlings after Alginite applications within three years of measurement, differentiated by tree species; significant differences among Alginite variants are indicated by different indices

3.3. Nutrient concentration in assimilation apparatus

Table 3 shows the concentration of nitrogen, phosphorus, potassium, calcium and magnesium in the dry matter of the assimilation apparatus of the species of interest according to the Alginite variants. Data showed that differences in the foliar nutrient concentrations between the variants were insignificant ($p>0.05$). Nitrogen concentration was higher in all four species treated with a variant with higher dose, while lower dose resulted in positive effects in Scots pine and English oak planted in the monoculture and mixture.

The phosphorus content was slightly higher on the plots treated with lower doses for both oak and maple. Only maple showed a higher phosphorus content in both variants B and C. English oak reflected an increased phosphorus content only for variant B on both mixture and monoculture plantings. Red oak responded negatively in case of both larger and smaller doses of Alginite. However, Scots pine did not respond irrespective of the doses of Alginite applied.

The amount of potassium in the dry matter was similar to that of nitrogen. English oak responded positively to both Alginite doses compared to the control treatment. Norway maple had a higher content only in the variant with an increased dose of Alginite. In red oak, the potassium amount was always smaller after application of Alginite. Scots pine reflected a small decrease of the potassium amount after application of Alginite.

Oak, in both cases (in mixture and monoculture) reacted negatively, with a reduced calcium content versus that of the control plot. Scots pine also reacted slightly negatively. In maple and red oak, the calcium content always increased only for a variant B.

The magnesium content in the assimilation apparatus proved to be less positive when compared to other elements. The increased amount of magnesium in dry matter occurred only in maple. English oak planted in a mixture did not show any changes in the magnesium content and in Scots pine, in which doses applied, were the same. Oak planted in monoculture indicated a reduced level of magnesium. A remarkably reduced magnesium content was recorded in red oak for variant B.

Tab. 3: Nutrient content in the assimilation apparatus and recommended value according to Bergmann

Species	Alginite	N (%)	± SE	P (%)	± SE	K (%)	± SE	Ca (%)	± SE	Mg (%)	± SE
Oak	A	1.84	0.19	0.19	0.02	0.62	0.03	1.93	0.24	0.21	0.01
Oak	B	**2.07**	0.19	**0.20**	0.02	**0.66**	0.03	1.75	0.24	0.18	0.01
Oak	C	**2.20**	0.19	0.18	0.02	**0.63**	0.03	1.42	0.24	0.18	0.01
Oak in mixture	A	2.00	0.19	0.20	0.02	0.63	0.04	1.76	0.17	0.19	0.01
Oak in mixture	B	**2.05**	0.19	**0.21**	0.02	**0.66**	0.04	1.59	0.17	0.19	0.01
Oak in mixture	C	**2.01**	0.19	0.19	0.02	**0.66**	0.04	1.71	0.17	0.19	0.01
Red oak	A	2.05	0.20	0.24	0.02	0.67	0.05	1.54	0.21	0.20	0.01
Red oak	B	2.05	0.20	0.18	0.02	0.65	0.05	**1.63**	0.21	0.19	0.01
Red oak	C	**2.27**	0.20	0.20	0.02	0.66	0.05	1.54	0.21	0.20	0.01
Oak Bergmann	-	2 - 3	-	0.15 – 0.3	-	1 – 1.5	-	0.3 – 1.5	-	0.15 – 0.3	-
Maple	A	2.13	0.18	0.18	0.03	0.67	0.03	1.56	0.18	0.17	0.01
Maple	B	2.07	0.18	**0.21**	0.03	0.63	0.03	**1.79**	0.18	**0.18**	0.01
Maple	C	**2.31**	0.18	**0.20**	0.03	**0.69**	0.03	1.35	0.18	**0.19**	0.01
Maple Bergmann	-	1.7 – 2.2	-	0.15 – 0.25	-	1 – 1.5	-	0.3 – 1.5	-	0.15 – 0.3	-
Pine	A	1.87	0.03	0.15	0.04	0.63	0.01	0.29	0.01	0.09	0.01
Pine	B	**1.92**	0.02	0.15	0.04	0.63	0.01	0.28	0.01	0.09	0.01
Pine	C	**1.89**	0.04	0.15	0.04	0.62	0.01	0.28	0.01	0.09	0.01
Pine Bergmann	-	1.4 – 1.7	-	0.14 – 0.3	-	0.4 – 0.8	-	0.25 – 0.6	-	0.1 – 0.2	-

Note: higher nutrient contents in variants with Alginite compared to control plots (without fertilizer) are highlighted; values according to Bergmann describe the first content value as a threshold sufficiency, the second value as a threshold excess; SE: standard error

3.4. Relationships among seedling parameters, nutrient contents and Alginite variants

The results of the PCA analysis are presented in the form of the ordination diagram (Fig. 3). The first ordination axis explained 39.1%, the first and second axes together explained 61.9%, and all four axes explained 86.7% variability of the data. The mortality was negatively correlated with mean height and showed a small correlation with with nitrogen and potassium. The contribution of nutrient contents to the mortality in 2013 and 2014 was relatively small. The application variants A, B, C showed low significance to the mutual relationships among seedling mortality, mean height increment and nutrient content in the assimilation apparatus compared to larger differences among the species. Differences among the variants were remarkable, especially for maple and red oak as marks of each record were relatively distant from one another, but marks for oak and pine were relatively closer together, in the diagram. Responses of tree species to the application of Alginite variants were different, when oaks variants with higher mortality in 2015 occupied the down-left part of a diagram, while higher increment were typical for maple and pine. Alginite application had a high positive effect on the mortality of seedling in the first year after planting. Generally, the best Alginite variant for height growth was a variant B.

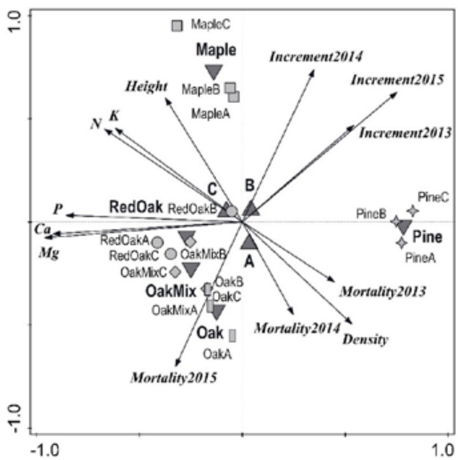

Fig. 3: Ordination diagram showing results of PCA analysis of relationships among number of seedlings (Density) and mean height (Height) at planting, seedling mortality (Mortality), mean height increment (Increment) in 2013, 2014 and 2015, nutrient content in the assimilation apparatus (N, K, Ca, P, Mg), tree species (Maple, Pine, Oak, RedOak, OakMix) and variants of Alginite application (A, B, C); small codes: ●, ◆, ■, ✦, ▮ indicate tree species with variants of Alginite application; large codes: ▲ ,▼ indicate tree species or variants of Alginite application

4. Discussion

One of the reasons why fertilizers are used in the forest crops is to reduce the mortality of seedlings in the first year, i.e. immediately after planting. There have been many studies carried out, focusing on the causes of plant mortality in the forest crops (Erafur et al. 2008; Barbeito et al. 2012). Some sorts of support for the planted seedlings on the marginal and abandoned agricultural lands, which might have the unfavourable site conditions, is often necessary (Kupka et al. 2015), and it becomes increasingly important with regard to a success of afforestation (Hatlapatková and Podrázský 2011). A positive effect of Alginite application on the seedling mortality in the first year after plantation corroborated the previously published results (Kupka et al. 2015; Tužinský et al. 2015). For example, mortality of red oak in the control sub-plots (control, variant A) was more than 7 times higher compared to that with the application of variant C. Difference of the mortality in response to treatment was not only significant for Scots pine, but there was a positive effect of both doses of Alginite (variants B and C). However, in the first year after planting an adverse trend has been reported for the Alginite application in Scots pine (Tužinský et al. 2015). In 2014, the mortality on all sub-plots treated with variants B and C were mostly higher than that of the control sub-plots, but this may not necessarily be caused by the mineral fertilizer but by climatic condition with higher temperature in April-June compared to the years 2013 and 2015 (Czech Hydrometeorological Institute Prague Kbely). In 2015, the results were unclear and positive effect of the Alginite application was manifested only for sub-plots planted with Scots pine.

Another important parameter, which reflects the response to the fertilizer application, is the height increment of seedlings. In the past, the effect of fertilizers on different tree species using wood ash or ash obtained from the peats was tested (Huotari et al. 2008; Pärn et al. 2009; Erfurt et al. 2011; Kikamägi et al. 2014). These studies have investigated the height increment of the seedlings during the first 2-4 years after planting; a positive influence of fertilizing by the ashes, however, was studied only on the forested areas. The sewage sludge is another fertilizer applied to forest crops, and those studies evaluated the sparsely wooded areas on agricultural land, which combine forestry and pasture. Evaluating the effect of sewage sludge in combination with nitrogen confirmed the increased height increment in red oak seedlings during the first four years after planting (Ferreiro-Dominguez et al. 2011). Another important study, which compared the use of sewage sludge compared to the control plots and the area fertilized with mineral fertilizers (by 500 kg to 8% N - 24% P_2O_5 - 16% K_2O per hectare) also confirmed the positive effect of sewage sludge on the height increment of seedlings (Rigueira-Rodríguez et al. 2010). Conversely, the use of sewage sludge in combination with lime has led to the positive results on seedling height increments (Mosquera-Losada et al. 2012). The effect of Alginite was only evaluated one year after planting, with a positive result in the height increment (Kupka et al. 2015; Tužinský et al. 2015). The evaluation of three-year old plantations showed, in general, a positive effect in plant growth after Alginite application. Concretely variant B had a positive effect on the height increment for all broad-leaved trees; more remarkably for maple, and these all positive effects may be comparable with those from the application of sewage sludge (Rigueira-Rodriguez et al. 2010; Ferreiro-Dominguez et al. 2011).

In addition, other materials, which are based on the algae extracts, have been proven as a convenient supportive matter for improvement of the growth of young plants in the forest nurseries (Lorenc et al. 2016). This study has shown that Bio-Algeen® preparate significantly improved the growth and development of the aboveground parts of seedlings, despite of the reduced mycorrhisation.

The nutrient content in the assimilation apparatus (organ) is one of the main factors that influence the growth of forest trees (Šrámek et al. 2009; Vacek et al. 2006, 2009; Truparová and Kulhavý 2011). The nutrient content in dry matter of the assimilation apparatus in the variants with different Alginite applications was not statistically conclusive. Only nitrogen reached higher values in the assimilation organs. Nitrogen is the key element, which increases the biomass production (Hejcman et al. 2007; Šrámek et al. 2009; Ring et al. 2013; Peragón et al. 2015). Furthermore, a trend has been observed with higher concentration of the major elements in the deciduous tree species (Hagen-Thorn et al. 2004; Šrámek et al. 2009) and most strikingly in the calcium. The actual supply of the major elements in the dry matter assimilation apparatus on the afforested agricultural land according to Bergmann (1993) showed values approaching, and often exceeding, the limit excess. In all deciduous tree species, lack of potassium was found, which might be due to the nature of the site or soil types.

5. Conclusion

The results of our study showed a significant positive effect of Alginite application on the mortality of seedlings in the first year after planting. The fertilization effect was rather smaller in the second year and the results were almost inconclusive in the third year. The positive effects were recorded in the height increment of the species of interest and significant differences were found among them, in general, after three year's period of the planting for Norway maple. Other tree species show unclear response patterns of the height increment in response to the application of Alginite, but Scots pine responded negatively. The nutrient contents in the assimilation apparatus showed insignificant differences. Afforestation of the marginal farmland is of growing importance, and therefore we need to pay more attentions to improve site environments and support the growth of forest crops. The application of organic sediments, such as Alginite could be one of the effective ways to enhance the growth of plantations, and therefore further research needs to be devoted to this topic in the future.

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