Ecological Engineering 167 (2021) 106270

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Survival and nutrient supply of seedlings of different tree species at the early stages of afforestation of a hard coal mine dump

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ARTICLE INFO

Keywords:
Mine dump
Reclamation
Topsoil
Seedlings
Nutrient supply
Scots pine
Norway spruce
Common oak
European beech

ABSTRACT

In Upper Silesia in Poland, coal is still exploited intensively and mine dump reclamation and afforestation are important environmental mitigation activities. In this study, we analysed the survival rate and foliar nutrient (N, P, K, Ca, and Mg) supply status and their quantitative relationships of two-year-old Scots pine, Norway spruce, Common oak and European beech at an early afforestation stage of a hard coal mine dump with topsoil. The conditions in the dump in the first years were particularly unfavorable for beech and spruce. The survival rate of seedlings varied between 93% for oak, 67% for pine, 30% for beech and 27% for spruce. Nutrient supply and their quantitative relationships in seedling foliage varied highly in all investigated species. The most deficient element was N; its content was lower than the accepted threshold for individual species under natural conditions. Of the soil properties analysed, electrolytic conductivity (EC) was strongly negatively correlated with foliar N and P. Thus, EC may be the factor with the highest negative effect on nutrient supply and the success of afforestation at early stages.

1. Introduction

The mining of coal and lignite, oil shale, mineral sand and rock, sulphur, and metallic mineral deposits has geomorphological, hydrological, and chemical effects on all ecosystem components. Globally, coal and lignite continue to play an important role in the energy mix, and post-mine landscapes are examples of large-scale transformation and human disturbance of ecosystems and are of worldwide interest and concern (Hüttl and Weber, 2001; Favas et al., 2018). From an ecological point of view, the goal of reclamation of post-mine sites is to develop a long-term sustainable ecosystem native to the disturbed area which would, moreover, possess all ecosystem functions and structure (Bradshaw, 1983). Due to landscape, soil, and water protection functions of new forests, afforestation seems to be the best developmental direction for post-mine sites (Zipper et al., 2011). Recently, the ability of new forests to capture and bind CO_2, which balances emissions from fossil fuel combustion, has also gained in importance (Pietrzykowski and Daniels, 2014).

The tree stand, which contributes to the formation of specific light, humidity and thermal conditions different from those in open spaces, is the basic element of restored forest ecosystems; it creates the right conditions for introduction of new plant and animal species into a given area (Prescott, 2002; Barbier et al., 2008). An appropriate assessment of habitat conditions and adjustment to the ecological requirements of trees has a significant impact on the composition of species selected for afforestation, and thus on the stability of new forests in reclaimed sites (Krzaklewski and Pietrzykowski, 2007; Pietrzykowski, 2014).

The growth and development of afforested landscapes and the quality of reconstructed tree stands in reclaimed sites are dependent on, and often limited by, adverse physicochemical properties of soils (Pietrzykowski et al., 2010; Jung et al., 2014; Pająk et al., 2016; Pająk et al., 2019). On mine dumps, waste rock deposition leads to vertical and horizontal mixing of carboniferous deposits. Consequently, coal mining waste and processing dumps typically display diverse grain sizes. Moreover, initial soils in mine dumps often have changeable chemical properties, especially salinity and pH (Schaaf, 2001; Knoche et al., 2002; Brevik, 2013), and frequently lack retention capacity (Strzyszcz and Harabin, 2004).

The basic factor that distinguishes minesoils from natural soils is the lack of soil organic matter (SOM; Pietrzykowski and Krzaklewski, 2007). Furthermore, the factor that affects the distribution of trees in response to soil nutrients on such a soil type is the deficiency of some basic

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https://doi.org/10.1016/j.ecoleng.2021.106270
Received 16 June 2020; Received in revised form 27 April 2021; Accepted 30 April 2021
Available online 4 May 2021

macronutrients, including nitrogen and phosphorus, and the simultaneous abundance of magnesium and potassium (Burger, 1994; Andrews et al., 1998; Heinsdorf, 1996).

Sulphuric acid is formed as a result of intensive oxidation of pyrites on mine dumps, and contributes to the lowering of pH. Lower soil pH decreases phosphorus absorption, and the deficiency of this element is compounded by the formation of amorphous iron oxides, which show high capacity for sorption of phosphorus ions (Katzur and Haubold-Rosar, 1996). In order to better recognise soil quality and to diagnose habitats, special minesoil quality indicators have been developed that take into account the physical and chemical characteristics of soils (Burger and Kelting, 1999; Pietrzykowski, 2010). All these aspects have contributed to the development of a method for mine dump reclamation which includes covering waste rock with a layer of about 40–50 cm of potentially fertile mineral deposits (Pietrzykowski and Krzaklewski, 2018). The main difficulty in implementing this method on a large scale is the availability of adequate amounts of fertile deposits. Currently, due to numerous ongoing road construction projects, there is an opportunity to obtain large quantities of soil which can be used to improve habitat conditions of the reclaimed dumps.

The establishment of mixed stands increases the biodiversity of forests. In addition, multi-species stands are better able to accumulate carbon, thus slowing down climate change more efficiently. These stands provide better protection against the effects of drought or floods. They are also friendlier habitats for various plant, animal and fungal species. Furthermore, deciduous tree species have higher resistance to diseases, pests and fires compared to coniferous monocultures (Kaar, 2002; Vares et al., 2004; Lõhmus et al., 2006). The introduction of deciduous species with higher impact due to litter fall facilitates the development of favourable soil humus properties (Woś et al., 2014).

Most reclaimed land in Central and Eastern Europe has been afforested with Scots pine monocultures. These monocultures make it possible to simplify soil preparation and the care of crops and stands. Moreover, the Scots pine is a pioneer species with a wide amplitude of ecological requirements, owing to which it has adapted to the extreme conditions prevailing in mine dumps. However, this species is sensitive to SO_2 concentrations in the air (Kozlov et al., 2002). As a recent study has shown, the current sulphur concentration in pine needles is positively correlated with the degree of tree crown defoliation (Likus-Cieślik et al., 2019). Therefore, in the case of post-mining sites with abundant soils, it is necessary to plan the reconstruction of species composition and gradual transformation of pine monocultures to multi-species communities, especially in the context of adapting forests to extreme weather phenomena, which are becoming increasingly important in times of climate change (Taeger et al., 2013).

To boost the success of afforestation of reclaimed sites, the share of deciduous trees in new stands should increase to at least 40% depending on habitat conditions (Kuznetsova et al., 2010). Years of experience have shown that the useful species for afforestation of coal mine dumps are the Common oak, European larch, which may be supplemented with an admixture of N-fixing species representing up to 5% of the composition of the introduced stands (Krzaklewski, 2017). In order to increase the effectiveness of reclamation treatments, it is important to increase biodiversity, which can be obtained by introducing species with different ecological requirements to the reclaimed site (Krzaklewski, 2017).

This paper presents an assessment of the survival rate, foliar nutrient (N, P, K, Ca, and Mg) supply status, and the quantitative relationships between foliar nutrients of two-year-old seedlings of several forest tree species, Scots pine, Norway spruce, Common oak, and European beech, at an early afforestation stage of a hard coal mine dump. The research hypothesis assumes that tree seedling nutrient supply at early growth can determine the survival and usefulness of species to hard coal spoil heap afforestation. This assessment would improve the afforestation strategies and successful restoration of novel ecosystems on spoil heaps in regions intensively mined for coal that is undergoing environmental transition.

2. Materials and methods

The experiment was located in the Upper Silesia Industrial District (GOP) on a part of the reclaimed dump of KWK Szczygłowice (South-West Poland; 50°12′22"N 18°41′28″E). Located in the northern part of the Upper Silesian Coal Region, the GOP is the largest industrial district in Poland; it has an area of 320,000 ha and includes 14 large cities with a population above seven million. Reclamation and afforestation are important strategies for environmental transformation of the coal-intensive Upper Silesia region (www.tracer-h2020.eu). This region receives on average 705 mm of total annual precipitation, and its average annual air temperature is 8.4 °C (https://meteomodel.pl). Currently, the reclaimed and afforested dump is partly administrated by the State Forest, Rybnik Forest District. The experiment, including an analysis of the adaptation and suitability of tree species, was launched in spring 2016 on a part of the reclaimed Szczygłowice coal dump. Before planting, the entire site underwent technical reclamation, by forming a slope made of carboniferous deposits (mostly shells and sandstone mixed with coal flotation spoil waste) and covering the dump with mineral soil to a thickness of 40 cm. The topsoil to cover the carboniferous deposits came from deeper sandy clay mineral horizons from a road construction project (the properties of the topsoil are provided below with the description of the soils of the dump). The experiment was fully randomized. On the prepared slope surface measuring 40 × 150 m, 36 plots (10 × 10 m) were set up, separated by a buffer strip of 2 m between the same species and of 4 m between different species (Fig. 1). (See Fig. 2.)

In total, 100 two-year-old seedlings with a covered root system, produced in a container with covered root system technology (Szabla and Pabian, 2003), were planted in each plot. Four species were tested: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* L.), Common oak (*Quercus robur* L.), and European beech (*Fagus sylvatica* L.). Nine plots were obtained for each species ($n = 9$). In order to protect the plantings against damage from deer and other herbivores, which is an important pressure limiting afforestation success, the entire experimental area was fenced.

2.1. Field research and measurements

In autumn 2018, biometric parameters were measured; seedling height (SH) and seedling diameter at a height of 5 cm above the root neck (DBH) were determined for ten seedlings selected diagonally from each plot. In addition, the survival rate of seedlings (SRS) was assessed. For this purpose, all live seedlings in a given plot were counted and then SRS was calculated:

$$SRS = \frac{SA*100\%}{\mathrm{SI}} \tag{1}$$

where SA was the number of seedlings alive, and SI was the number of introduced seedlings ($N = 100$).

Foliage samples were collected (about 15 oak and beech leaves, 15 pairs of pine needles, and 30 spruce needles) from each measured seedling. Samples were placed in sealed plastic bags, transported to the laboratory, and stored in a refrigerator at 4 °C for up to two weeks.

To determine the soil properties of each plot, mixed soil samples were collected from the top mineral soil (0–40 cm) and from the waste rock horizons (40–80 cm) from five regularly distributed points (four in each corner and one in the middle of the plot).

2.2. Laboratory analyses

Soil samples were air-dried and sieved (2 mm mesh) and the following characteristics were determined: particle size distribution using a Fritsch GmbH Laser Particle Sizer ANALYSETTE 22; electrical

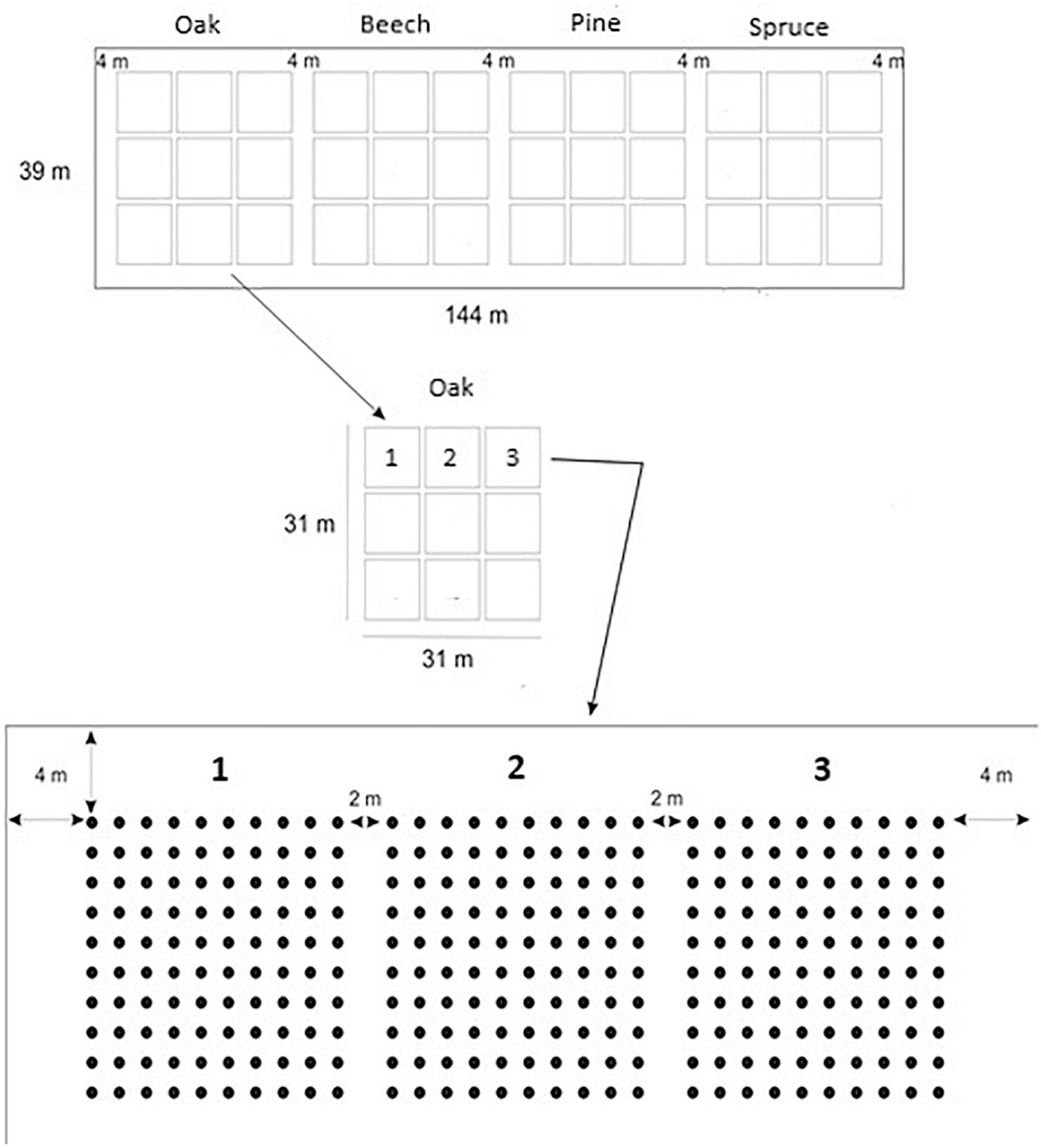

Fig. 1. The scheme for the experiment set up on a hard coal spoil heap.

conductivity (EC) measured conductometrically and pH measured potentiometrically at 21 °C; and soil organic carbon (SOC) and total nitrogen (Nt), analysed using a LECO TruMac CNS analyser. Base cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) were extracted in 1 M CH_3COONH_4 (pH = 7). The concentrations of Na^+, K^+, Ca^{2+}, and Mg^{2+} in the extracts were measured using atomic absorption spectrometry with an inductively coupled plasma optical emission (ICP-OES) spectrophotometer (iCAP™ 6000 Series).

Foliage samples (current-year needles of coniferous species and leaves of deciduous species) were successively cleaned with deionised water. Next, pooled samples were prepared for a given plot and dried at 105 °C. The N and C content of the foliage was determined with a LECO TruMac CNS analyser. Nutrients (Ca, Mg, K, and P) in the foliage were measured with an ICP-OES spectrophotometer (iCAP™ 6000 Series) after digestion in a 3:1 mixture of HNO_3 and $HClO_4$.

2.3. Statistical analyses

Statistical analyses using Statistica 13 software (StatSoft, Inc., 2017) included Pearson correlation analysis and multiple regression between soil parameters and the survival rate of seedlings introduced to the reclaimed hard coal mine dump. The differences between mean values for silt (0.05–0.002 mm), clay (<0.002 mm), pH(H_2O), pH(KCl), EC, and Ca^{2+}, K^+, Mg^{2+}, and Na^+ in soil and nutrient (N, P, K, Ca, and Mg) content in the foliage were tested using the Tukey RIR test (at $p < 0.05$). Prior to the Tukey test, the data were log-transformed, checked for normal distribution using the Shapiro–Wilk test and for homogeneity of variance with Brown–Forsythe test. In addition, principal component analysis (PCA) was performed to determine the factors affecting the supply of nutrients (N, P, K, Ca, and Mg) and their quantitative ratios.

3. Results and discussion

3.1. Basic soil properties

In the spatial arrangement of the experiment, the topsoil layers (0–40 cm), which covered the mining waste, did not vary significantly in pH, EC, and C, S, Ca and Na content. There were substantial differences in grain size between the plots of the investigated species. The silt content ranged from 30% (the oak plots) to 76% (the pine plots), and the clay content from 19% (the pine plots) to 58% (the oak plots). Plots planted with beech and oak had higher N content than those planted

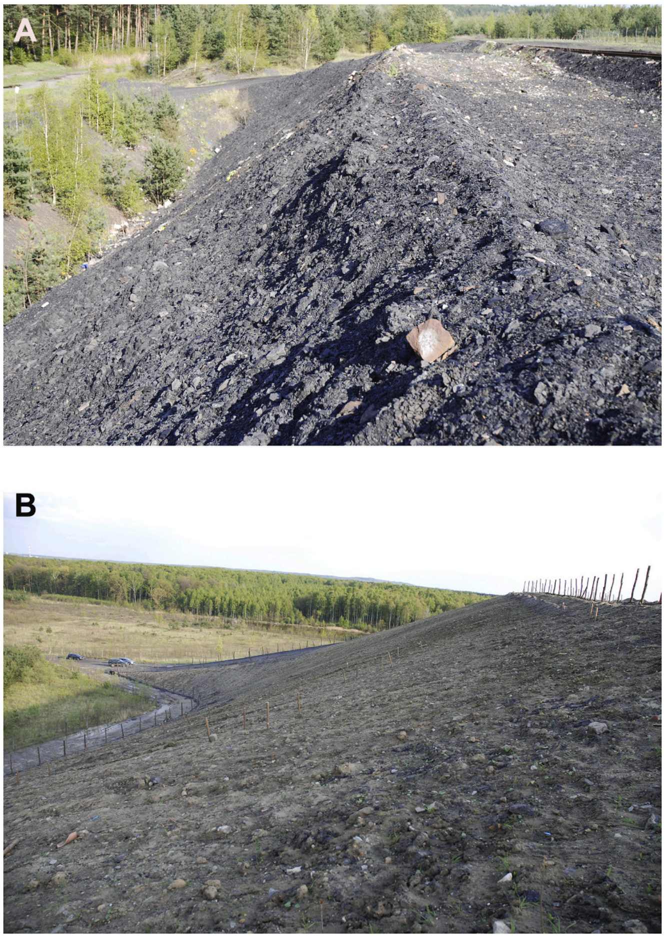

Fig. 2. (a) General view of the slope of the hard coal spoil heap before reclaiming and covering with topsoil (April 2016). (b) The experimental plots afforested with different tree species after applying topsoil and fencing off to exclude herbivores (May 2016).

with spruce and pine. In addition, K and Mg content was higher in plots planted with beech than in those planted with spruce (Table 1).

Waste rock deposited on the dump was alkaline (pH = 7.41) and did not differ from the established research plots in EC and N, C, S, Ca, Na, K and Mg content. These layers displayed significant spatial differentiation of grain size. The silt content in the investigated horizon (from 40 to 80 cm) ranged from 35% (the spruce plots) to 79% (the pine plots), and the clay content ranged from 18% (the pine plots) to 51% (the spruce plots; Table 1).

3.2. Biometric parameters and seedling survival rate

The seedlings of the investigated species did not differ significantly in thickness measured 5 cm above the root neck (DBH; 0.45–0.52 cm); however, they clearly differed in height (SH). The tallest were spruce seedlings (34.5 cm) and the oaks were the shortest (19.5 cm). These parameters resulted mainly from the characteristics of the planting material and ecological properties of the investigated species (Farjon and Filer, 2013). When trees are under canopy experience a decrease in the amount of solar radiation which is absorbed by the chlorophyll. Changes resulting from light deficiency cause a reaction in light-requiring plants such as pine, consisting of elongation of the stem and needles while reducing the number of branches and chlorophyll in the leaves (Pierik and de Wit, 2014). Shade-tolerant species, on the other hand, produce thinner leaves with a higher chlorophyll content in order to increase photosynthesis efficiency in light deficiency (Franklin, 2008). The reduced height growth of pine and oak in our study is consistent with the results of previous studies. Pine seedlings grown under low sunlight characterized by the highest altitude increases (Riikonen et al., 2016; Sarala et al., 2011). Furthermore, in accordance with previous findings sunlight does not affect the diameter of the stem (Riikonen et al., 2016; Sarala et al., 2011). Differences in tree survival rate are more important in the initial period of cultivation for assessing the suitability of species for afforestation of dumps. The SRS of the investigated species differed: it was 93% for oak, 67% for pine, 30% for beech and 27% for spruce (Table 2).

In the first years after the seedlings were introduced, they were at the highest risk from drought and strong insolation; hence, the ecological properties of individual species classified as pioneers and climax are of great importance (Grime, 2001; Pietrzykowski, 2014). Soil is a key factor in determining the sensitivity of seedlings to water deficit. Spruce

Table 1
The mean values (± SE) for basic soil properties under the four seedling species. Different letters indicate significant differences (one-way ANOVA, Tukey test, $p < 0.05$).

Soil layer	Species	Silt (0.05–0.002 mm)	Clay (<0.002 mm)	$pH_{(H2O)}$	$pH_{(KCl)}$	C	N	S	EC	Ca^{2+}	K^{+}	Mg^{2+}	Na^{+}
		[%]					%		[μs cm^{-1}]		[$cmol_{(c)}$ kg^{-1}]		
0–40	Pine	76 ± 6^{a}	19 ± 5^{a}	8.1 ± 0.0	7.5 ± 0.0	1.43 ± 0.04	0.05 ± 0.00	0.01 ± 0.00	120.7 ± 6.0	286.9 ± 6.2	7.3 ± 0.2^{ac}	22.3 ± 0.7^{ab}	5.6 ± 0.4
40–80	Pine	79 ± 7^{b}	18 ± 6^{bc}	7.6 ± 0.1	7.2 ± 0.1	9.51 ± 0.94	0.24 ± 0.02	0.30 ± 0.03	466.7 ± 87.0	118.9 ± 7.3	25.2 ± 1.1	40.1 ± 2.5	25.7 ± 7.8
0–40	Spruce	45 ± 12^{b}	45 ± 10^{b}	8.1 ± 0.0	7.6 ± 0.0	1.47 ± 0.09	0.05 ± 0.00	0.01 ± 0.00	119.4 ± 4.3	273.0 ± 5.1	6.6 ± 0.2^{a}	20.7 ± 0.9^{b}	6.2 ± 0.6
40–80	Spruce	35 ± 12^{a}	51 ± 10^{a}	7.5 ± 0.1	7.1 ± 0.1	8.17 ± 0.36	0.23 ± 0.01	0.35 ± 0.02	375.0 ± 27.3	100.5.0 ± 7.8	24.2 ± 0.9	39.6 ± 1.5	22.5 ± 2.3
0–40	Beech	34 ± 3^{b}	55 ± 3^{b}	7.9 ± 0.2	7.5 ± 0.0	1.71 ± 0.10	0.06 ± 0.00	0.01 ± 0.00	123.0 ± 5.2	291.7 ± 7.9	8.1 ± 0.1^{bc}	24.3 ± 0.4^{a}	6.7 ± 0.3
40–80	Beech	63 ± 4^{ab}	27 ± 3^{bc}	7.3 ± 0.1	7.0 ± 0.1	9.62 ± 0.64	0.27 ± 0.01	0.39 ± 0.03	382.2 ± 33.6	113.2 ± 10.6	24.7 ± 1.1	36.0 ± 2.6	16.2 ± 1.5
0–40	Oak	30 ± 3^{b}	58 ± 2^{b}	8.1 ± 0.0	7.5 ± 0.0	1.68 ± 0.08	0.06 ± 0.00	0.01 ± 0.00	137.7 ± 7.1	292.2 ± 4.9	8.1 ± 0.2^{b}	23.7 ± 0.4^{a}	7.1 ± 0.4
40–80	Oak	50 ± 6^{ab}	39 ± 5^{ac}	7.4 ± 0.1	7.0 ± 0.1	10.28 ± 0.59	0.27 ± 0.01	0.41 ± 0.03	402.0 ± 29.9	109.5 ± 8.7	25.4 ± 0.9	40.0 ± 1.6	21.4 ± 3.7

C – soil organic carbon; N – total nitrogen; EC - Electrical conductivity; Pine – Scots pine; Spruce – Norway spruce; Beech – European beech; Oak –Common oak.

Table 2
Biometric parameters and the mean values (± SE) for nutrinets content in foliage of the studied tree species. Different letters indicate significant differences (one-way ANOVA, Tukey test, $p < 0.05$).

Species	DBH	Seedling height	Survival rate of seedlings	N	P	K	Ca	Mg	N/P	N/K	N/Ca	N/Mg	P/K	P/Ca	P/Mg	K/Mg
	cm	cm	%	%												
Pine	0.47 ± 0.01^{a}	27.1 ± 1.1^{b}	67 ± 3^{b}	1.56 ± 0.03^{ac}	0.14 ± 0.00^{a}	0.50 ± 0.02^{a}	0.37 ± 0.03^{b}	0.12 ± 0.00^{a}	11.3 ± 0.1^{b}	3.1 ± 0.1^{a}	4.4 ± 0.3^{a}	13.4 ± 0.5^{a}	0.3 ± 0.0^{a}	0.4 ± 0.0^{a}	1.2 ± 0.1^{a}	4.3 ± 0.2^{a}
Spruce	0.52 ± 0.02^{a}	34.5 ± 0.8^{c}	30 ± 4^{a}	1.38 ± 0.04^{c}	0.16 ± 0.01^{a}	0.48 ± 0.02^{a}	0.81 ± 0.02^{c}	0.13 ± 0.00^{a}	9.0 ± 0.2^{c}	3.0 ± 0.1^{a}	1.7 ± 0.1^{b}	10.8 ± 0.4^{b}	0.3 ± 0.0^{b}	0.2 ± 0.0^{b}	1.2 ± 0.1^{a}	3.7 ± 0.2^{a}
Beech	0.47 ± 0.01^{a}	20.2 ± 1.2^{a}	27 ± 6^{a}	1.13 ± 0.06^{b}	0.11 ± 0.06^{b}	0.55 ± 0.02^{a}	1.16 ± 0.04^{a}	0.21 ± 0.04^{b}	10.0 ± 0.2^{a}	2.1 ± 0.1^{b}	1.0 ± 0.1^{c}	5.3 ± 0.2^{c}	0.2 ± 0.0^{c}	0.1 ± 0.0^{c}	0.5 ± 0.0^{b}	2.6 ± 0.2^{b}
Oak	0.45 ± 0.02^{a}	19.5 ± 1.3^{a}	93 ± 2^{c}	1.58 ± 0.06^{a}	0.15 ± 0.00^{a}	0.72 ± 0.02^{b}	1.29 ± 0.06^{a}	0.18 ± 0.00^{c}	10.4 ± 0.3^{a}	2.2 ± 0.1^{b}	1.3 ± 0.1^{bc}	8.6 ± 0.3^{d}	0.2 ± 0.0^{c}	0.1 ± 0.0^{c}	0.8 ± 0.0^{c}	3.9 ± 0.1^{a}

DBH – Seedling diameter at a height of 5 cm above the root neck; Pine – Scots pine; Spruce – Norway spruce; Beech – European beech; Oak –Common oak.

is not able to survive long periods of extreme drought, especially on mineral soils. Due to the limited rooting depth, spruce seedlings are more likely to suffer from a higher mortality rate (Matisons et al., 2021).

Among the investigated species, the conditions in dumps in the first years after reclamation are particularly unfavorable for beech and spruce because they require rather moist soils and grow well in partial shade in the shelter of forest trees and, consequently, may be damaged by intensive sun light (Boratyński and Bugała, 1998). However, these species may be of great importance at a later stage of mixed stand development; therefore, they are worth investigating under the conditions of afforested dumps. The good survival rates of oak and pine demonstrate their high usefulness for afforestation of dumps. In addition, an improvement in air quality, including a significant reduction in SO_2 concentration in the air, has been observed in the GOP region (Likus-Cieślik et al., 2019); this provides greater opportunities to use pine as a pioneer species in dump afforestation than in the past (the 1970s and 1980s), when environmental pollution in the Upper Silesia Region was severe (Dmuchowski and Bytnerowicz, 1994) and especially SO_2 emissions led to dieback of coniferous species in forests.

Furthermore, the SRS of pine was positively correlated with the potassium ($r = 0.83$) and magnesium ($r = 0.92$) content of the soil, and that of spruce with soil pH ($r = 0.78$). The SRS of beech was negatively correlated with soil pH ($r = -0.71$) and positively correlated with silt content ($r = 0.68$). Not demonstrated the interaction of different soil properties (silt $_{(0.05–0.002\ mm)}$, clay $_{(<0.002\ mm)}$, EC, Ca^{2+}, K^{+}, Mg^{2+}, and Na^{+}) on the SRS of individual tree species.

3.3. Mineral nutrition status and quantitative nutrient relationships of foliage

The nutrient supply status of the seedlings of the investigated tree species varied. The nutrient content of foliage is one of the most important criteria for assessing the adaptability of forest tree seedlings to changing environmental conditions (Vares et al., 2004; Lõhmus et al., 2006). When the supply of nitrogen and phosphorus decreases and the demand for them increases, plants retranslocate these nutrients from leaves, especially from older leaves, leading to a reduction in their rate of photosynthesis and acceleration of their ageing (Lambers and Oliveira, 2019). The leaves of oak seedlings under study site conditions contained more K, Ca, and Mg than the foliage of the other tree species investigated. The pine and spruce seedlings had the same amounts of N, P, K, Mg. The species with the lowest nutrient content was beech (Table 1). Of the soil properties analysed, EC negatively affected the N and P content of leaves. EC disrupts plant development by limiting nutrient and water uptake. The interaction between the salts present in the soil solution contributes to the appearance of ionic stress in plants. This leads to inhibition of plant growth (Munns et al., 2006). In addition, higher Mg concentrations in the foliage in all cases were associated with lower N and P content. This is due to the antagonistic interaction of magnesium ions with potassium and nitrogen ions, which react synergistically. In addition, the potassium content of the plant increases with soil acidification. As the acidity of soils decreases, magnesium uptake by plants and its concentration within plant tissue increase (Gunes and Welch, 1989). A positive correlation was also noted between pH and the phosphorus content in pine and oak seedlings. The other soil parameters analysed (silt $_{(0.05–0.002\ mm)}$, clay $_{(<0.002\ mm)}$, K^{+}, Mg^{2+}, and Na^{+}) did not have a significant impact on the nutrient content of the investigated species. The demonstrated spatial differentiation of the grain size of the topsoil horizon (0–40 cm) in the plot arrangement also did not affect mineral nutrition.

Of the nutrients analysed, the most deficient was N, whose content was lower than the accepted threshold for individual species. The optimal N content for pine is 2.4%–3.0%, for spruce 1.8%–2.4%, for beech 1.76%–2.60%, and for oak 2.0%–3.0%. The soils that the seedlings grew on were also characterized by low nitrogen content, which may result in a limited supply of this element. Furthermore, the beech and pine seedlings were deficient in P, while in beech, oak and pine seedlings the deficient element was K. The seedlings in this study had a sufficient or higher supply of Ca and Mg compared to natural conditions and managed forest sites (Baule and Fricker, 1973; Fober, 1993). The N and P supplies of the pine seedlings investigated were lower than those of four-year-old pine seedlings from a reclaimed former oil shale pit (Kuznetsova et al., 2010). On extremely barren sands, the nutrient content of pine at 1.21% N, 0.5% K, 0.11% P and 0.09% Mg was comparable to that of the pine seedlings in this study (Pietrzykowski et al., 2013). The N supply in the managed forests of north-west Austria ranged from 1.87% to 2.39% for beech and from 2.07% to 2.65% for oak. The Ca, Mg and K content in beech and oak was higher than that in the tree species in our study (Kazda et al., 2004). Soil microorganisms are particularly competitive in obtaining nutrients in soils with low nitrogen and phosphorus concentrations. By immobilizing phosphorus, microorganisms contribute to reducing the availability of phosphorus to trees. Under identical soil and habitat conditions, the phosphorus supply of beech seedlings may be significantly greater than the phosphorus supply of spruce seedlings (Göttlein, 2015; Prietzel, 2020).

In assessing the nutritional status of trees, not only the foliar content of individual elements but also their proportions are significant (Baule and Fricker, 1973; Pietrzykowski et al., 2013). The nutrient ratios in the foliage were highly variable. The N:P:K:Ca:Mg ratio (assuming $N = 100$) for pine was 100:9:32:23:7, for spruce 100:12:35:58:9, for beech

100:10:49:102:19, and for oak 100:9:46:82:11. Furthermore, the SRS of oak was correlated with the N content of the leaves ($r = 0.78$) and with the N:K ($r = 0.68$), N:Mg ($r = 0.81$) and N:Ca ($r = 0.71$) ratios. Over a period of 10 years (from 2000 to 2010), the nitrogen to phosphorus ratio in the forests of Europe has increased: for beech, from 3.9 to 20.3; for oak, from 8.2 to 18.9; for spruce, from 3.0 to 9.5; and for pine, from 3.4 to 11.1 (Jonard et al., 2014). In European forests, high N deposition is currently being observed, which may affect the nutritional status of P whose primary source in the soil is parent rock minerals (Frossard et al., 2011). High availability of N increases tree growth, which at the same time increases the need for other nutrients such as P. In addition, increased availability of N reduces root biomass and negatively affects the development of mycorrhizae (Nilsson and Wallander, 2003; Kjøller et al., 2012). The quantitative relationships between N and Mg in the seedlings of the species investigated in this study may be due to increased availability of Mg in the soil. A disturbance in the quantitative relationships between elements, in particular the N:P ratio of the species investigated, may cause health problems for trees, as shown by Veresoglou et al. (2014).

4. Conclusion

The survival rate of Scots pine, Norway spruce, Common oak and European beech seedlings varied significantly under conditions at the early stages of afforestation of a reclaimed coal mine dump. The nutrient content in tree foliage under the conditions in reclaimed coal mine dumps varied in comparison to that under natural and managed forest site conditions. One of the most important factors determining nutrient supply was soil EC, as salinity and elements forms content, i.e. related to the soil solution. In addition, the factors that determined the rate of survival of seedlings in the early stages of afforestation were the ecological properties of individual species belonging to pioneer and climax species groups. These findings are highly important for afforestation goals and strategies and the species composition of introduced tree stands, where pioneer species have to be established at an early stage of the new forest development.

Declaration of Competing Interest

None.

Acknowledgements

We are grateful to Dawid Leńczuk MSc, Kacper Paturej MSc, Patrycja Pisarska MSc and the staff of the Rybnik Forest Inspectorate, State Forests (Lasy Państwowe) for their field work assistance in the experimental plots. We thank Iwona Skowrońska MSc for laboratory analysis. This research is part of project no. EO.271.3.11.2019, entitled 'Mobilny automat do leśnych prac odnowieniowych oraz zalesiania terenów porolnych i rekultywowanych (RoboFoR)' (A mobile automatic device for forest regeneration tasks and afforestation of former farmland and reclaimed areas [RoboFor]). The project was financed by the Regional Directorate of State Forests in Warsaw.

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