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INFLUENCE OF SOIL FERTILITY ON THE ABILITY OF SCOTS PINE (*Pinus sylvestris* L.) TO ADAPT TO TECHNOGENIC POLLUTION

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HIGHLIGHTS

The null hypothesis of the research is to test whether soil fertility in technogenic contaminated areas is an important factor for adaptation of Scots pines.

Different soil fertility allowed us to estimate the effect of soil factor on the ability to adapt to magnesite pollution.

The annual growth rings of Scots pine growing on soils of different fertility were significantly different under the same level of technogenic pollution.

Soil fertility allows better adaptation of Scots pine to low temperatures, and more actively grow on sites with increasing precipitation.

Keywords:
Scots pine
Forest planting
Dendrochronological analysis
Forest ecosystem
Aero-technogenic

ABSTRACT

The purpose of the research is to identify the effect of soil factor on the ability of Scots pine to adapt to technogenic pollution based on comparative analysis of radial increment of the species which grows on soils of different fertility. The null hypothesis that soil fertility is a significant factor for adaptation was tested. The research area i.e. the plantation created in 1983 and exposed to pollution of aero-technogenic emissions of magnesium production Satka/Chelyabinsk Region/Russia, is located within the central part of the subzone of coniferous-broad-leaved and South-taiga coniferous forests of the Southern Urals. The analysis of annual growth rings (AGR) of Scots pine growing on soils of different fertility allowed us to estimate the effect of soil factor on the ability of Scots pine to adapt to magnesite pollution. As results of the research it was found that the differences in the AGR of Scots pine growing on soils of different fertility was statistically significant under the same level of technogenic pollution. During the investigation period (1994-2010), the AGR of Scots pine on fertile soils were significantly higher than those of on poor soils for 7 years. It was revealed that the positive effect of soil fertility on the Scots pine growth is leveled at the level of pollution exceeding 6-10 thousand tons per year of gaseous emissions and 25-30 thousand tons per year of total emissions. It was also found that soil fertility allows better adaptation of Scots pine to low temperatures, and more actively grow on sites with increasing precipitation.

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INTRODUCTION

Development of the industry leads to a progressing increase in emissions in atmospheric air. As a result, large areas of forest ecosystems have become under the influence of aero-technogenic pollution, thus, and the assessment of development of degressive tendencies and ability of organisms and ecosystems to adapt to this influence is needed. Steady management of bioresources and understanding of mechanisms of stabilization of the biosphere depends on the solution of this problem (MAITI et al., 2016). The exponential growth of these relevant studies raise the number of potential citers and therewith the probability of relevant papers to be cited (HAUNSCHILD et al., 2016). Special attention has been given to adaptation of woody plants to city conditions and industrial pollution (DISE and GUNDERSEN, 2004; SUKHAREVA, 2013; BUHARINA and DVOEGLAZOVA, 2016, MIKHAILOVA et al., 2017; MAKHNIOVA et al., 2019; MENSCHIKOV et al., 2019; POTAPENKO et al., 2019), as well as to the features of interference in the system of the ecosystem-soil during pollution (MENON et al., 2007; OROZCO-ACEVES et al., 2015; BENNETT et al., 2017). It is suggested that mineral food of plants has a positive impact on their adaptation to adverse effects of the environment (HABAROVA et al., 2015; MAITI and RODRIGUEZ, 2015).

In the recent years, the dendroindicative method of research in forest ecosystems has actively developed (ANONYMOUS, 1990a; SHIYATOV et al., 2000). Annual rings of tree species show regularities of influence of external environmental conditions, and it has allowed making existential assessment of change of forest ecosystems for many years. With this method, it is possible to reveal a negative or positive influence of various factors of the environment that hinder or improve the radial gain of tree species.

Technogenic factors in the modern world increasingly affects the ecosystem. One of the main sources of technogenic emissions to the atmosphere in the Urals, in Russia is the Plant Magnesite. The main purpose of this research was to reveal the influence of the soil factors on the ability of the Scots pine (*Pinus sylvestris* L.) to adapt to technogenic (magnesite) pollution. The basis of the comparative analysis of annual growth rings (AGR) in the Scots pine plantations that grow on soils of various fertility was followed. It should be noted that the plantations were even-aged, and exposed to a same level of pollution. It was hypothesized that the fertility of soils is a significant factor for adaptation of the Scots pine individuals to the pollution. The scientific novelty consists in the proof of statistical reliability of differences in the radial gain of the Scots pine, which grows on soils of various fertility at the identical level of technogenic pollution.

MATERIAL AND METHODS

Investigation area

The Scots pine plantation established in 1983 was selected as the research area since it has been exposed to pollution of aero technogenic emissions of magnesite production (Satka, Chelyabinsk region, Russia, 55^0 05' N, 59^0 03' E) (Figure 1). The Scots pine plantation consist of 5 experimental sites (ES) with a total area of 6 hectares. In this work we studied two experimental sites No. 5 and 6 with an area of 1 and 0.5 hectares, respectively. The characteristics of experimental sites (ES) which are situated 3 km from the pollution source in moderately polluted zone on soils of various fertility, have been shown in Table 1 and 2.

Experimental sites are situated along the main path of the dust. The research area is characterized by continental climate with moderately cold winters and warm, sometimes hot summers. In spring, sharp

FIGURE 1 Location of the investigation area.

TABLE 1 Characteristics of the experimental sites and soil (material by MENSCHIKOV, 1985).

ES	Location of the site on the slope	Aspect	Slope	Water nutrition	Depth of humus horizon (cm)	Soil texture
5	on the upper part of the slope	south	3-50	feed from precipitation	5	sandy loam
6	on the lower part of the slope	east	3-40	feed from precipitation, underground water	30	medium-textured loam

TABLE 2 Chemical characteristics of the soil of the experimental sites.

ES	Soil fertility	pH* H2O	Humus, ** %	P_2O_5** mg·kg^{-1}	K_2O** mg·kg^{-1}	Relation* Mg^{++}/Ca^{++}
5	poor	8.5	3.1	56	110	2.7
6	fertile	8.3	9.5	70	170	0.9

differences from negative to positive temperatures are characteristic. The vegetation period begins in late April. Along with it, in May and even in June, it is frequently cold weather connected with the Arctic air. The cold snap quite often is followed by plentiful snow. The late spring frosts are noted at the end of May and the beginning of June while the first autumn frosts usually occur in early September. The fall season is quite warm while the early autumn is characterized, as a rule, by steady clear weather. Average annual air temperature is 0.7 ^{0}C. The total annual rainfall is 555 mm in average. The highest amount of precipitation occurs during the summer period (about 45% of the annual precipitation, mostly in July) whereas in winter their quantity decreases sharply (26% of the annual precipitation, the lowest in February). The data of the meteorological station, which is located 40 km from the source of emissions of Zlatoust, were used (ANONYMOUS, 1990b). According to B.P. Kolesnikov's (1969) district division, the study area belongs to the central part of the sub band of coniferous and broad-leaved, and South-taiga coniferous forest zones of South Ural.

METHODS

Breast height diameters (cm) of trees on sample plots in each experiment sites were measured at 1.3 m above the ground with an accuracy of 0.1 cm. Height of trees was measured using a Haglof altimeter with a precision of 0.20. Comparisons were made using the F-test for the height and diameter measurements obtained from the treatments. Life expectancy of needles was determined by visual assessment of shoots based on the number of interned internees. Escape from fully preserved needles taken equal to one, with partially preserved one-tenth of the unit. The age limit was determined by summing all values. Observations were made on 15-20 tree shoots in the upper third of the tree crown (GRUBER, 1988). Crown defoliation and crown condition, as well as damage to the stand, of each tree was recorded as outlined in Menschikov (2001). This technique was described in detail in our previous research (ZAVYALOV et al., 2018).

The forest stand damage index on the site was calculated as the average value of the categories (classes, points) of the state from 100 to 120 main trees counted on the experimental site using the equation 1, where: n_{1-6} – Number of trees I, I – IV category (damage classes); K_{1-6} – The points of the living condition of the categories of trees corresponding to the category number (damage class); *N* – The total number of recorded trees on the sample area.

$$Ip = \frac{n_1K_1 + n_2K_2 + ... + n_6K_6}{N} \quad [1]$$

In mixed stands, the damage index was determined separately for each tree species. Then, a general index in average was calculated for each stand.

The core samples were taken using the Swedish increment borer at about 30 cm height from two root necks from each tree. Collecting, transportation and preprocessing of cores were carried out with standard techniques, which are well accepted in dendrochronology studies (ANONYMOUS, 1990a; SHIYATOV et al., 2000). Measurement of width of annual rings was conducted by the measuring LINTAB 6 complex with an accuracy of 0.01 mm. All annual growth rings were cross-dated visually in TSAP-WIN package (RINN, 1996). For the analysis, radial increment from 1994 to2010 were used. The statistical relationships between the radial growth of the Scots pine and fertility of soils were tested using the analysis of variance (ANOVA), and correlation analyses at $p<0.05$ (KHALAFYAN, 2010). Calcium and magnesium metals from the soil were extracted with acetate-ammonium buffer solution. Concentrations of calcium and magnesium were determined using an atomic absorption spectrometer. Phosphorus and potassium were extracted from the soil using ammonium carbonate. Concentrations of potassium were determined using an atomic absorption spectrometer. Concentrations of phosphorus were determined using a photo electrocolorimeter. pH was determined on the ionometer. The method of determination of organic matter is based on the oxidation of organic matter with a solution of potassium bicarbonate in sulfuric acid and the subsequent determination of trivalent chromium equivalent to the content of organic matter on a photo electro colorimeter.

RESULTS AND DISCUSSION

The study of the influence of magnesite pollution on the state and growth of the Scots pine has been carried out since 1984. Long-term study of this pollution has shown that influence of emissions of magnesite pollution leads to decrease in growth and deterioration in the state of both mature natural pine forest stands (ZAVYALOV, 2015), and forest planting, which grow 3 km from the pollution source on soils of various fertility, are studied for *Pinus sylvestris* L., *Larix sukaczewii* Dylis, *Betula pendula* Roth (ZAVYALOV and MENSCHIKOV, 2016; ZAVYALOV et al., 2018), decrease in elevated biomass of *Betula pendula* Roth (ZAVYALOV and MENSCHIKOV, 2010), increase in xeromorphy of leaves and Mg in leaves (ZAVYALOV, 2013), weak influence of the pollution on sowing qualities of seeds of *Pinus sylvestris* L. (MOHNACHEV et al., 2013) and on natural regeneration of *Pinus sylvestris* L. (MOHNACHEV et al., 2018), but noticeable decrease in radial gain in this tree species (ZAVYALOV, 2018). In the course of work, the zero hypothesis that the fertility of soils is a significant factor for adaptation of the Scots pine to pollution was supported. As it has been noted, forest stands on rich soils have the best height and diameter growth (Table 3). The study was also devoted to check of this hypothesis on statistical reliability.

TABLE 3 Indicators of experimental cultures of Scots pine.

ES	Diameter (cm)	Height (m)	Average index of damage	Term of needles life	Defoliation
5	7.2±0.33	6.9±0.20	2.66±0.08	3.4±0.07	45±2.04
6	9.7±0.75	7.2±0.49	3.13±0.18	2.8±0.11	47±4.72

The dispersive analysis, which was carried out every year during the study, has revealed statistical reliability of differences in radial growth of Scots pine in 1994, 1997, 1998, 1999, 2000, 2001 and 2002. These years' radial gains of Scots pine on rich soils were bigger in comparison with the gain on poor soils (Table 4). It exhibits the statistical importance of the factor of fertility for adaptation of plants to pollution.

The lack of reliable differences in growth in other years allows carrying out the analysis of restrictions of adaptation ability of Scots pine, connected with other external natural and technogenic factors. For these purposes, we have carried out the correlation analysis, and monitored the influence of the external factors on the level of differences in radial gains of Scots pine growing on poor and rich soils. Coefficients of Spearman correlations for significance value of distinctions (the values *p* given in table 4), and a number of natural and technogenic factors are calculated. The results of the correlation analysis are given in table 5.

Statistically significant correlations (*p<0.05*) were shown by emissions - general and gaseous ones (technogenic factors), average temperatures in May-August, the sum of positive temperatures, average monthly rainfall and the sum of precipitation a year, average monthly rainfall and the sum of precipitation from September of the previous year to August of the current year (Table 5).

TABLE 4 Dispersion analysis of the dependence of the radial growth of Scots pine on soil fertility .

Nº ES	Average AGR	-95%	+95%	F-test** (1.77)	p
		1994 year			
5	251	232	271	11.42	0.0011*
6	320	276	365		
		1995 year			
5	317	294	341	0.34	0.56
6	331	285	376		
		1996 year			
5	255	238	271	0.64	0.43
6	268	232	304		
		1997 year			
5	200	185	215	16.46	0.0001*
6	266	229	303		
		1998 year			
5	129	115	143	16.37	0.0001*
6	192	157	227		
		1999 year			
5	104	91	117	29.84	0.0001*
6	194	152	237		
		2000 year			
5	94	81	107	64.19	0.0001*
6	241	189	292		
		2001 year			
5	91	76	106	67.72	0.0001*
6	239	193	285		
		2002 year			
5	133	113	154	23.29	0.0001*
6	228	195	261		
		2003 year			
5	182	156	207	3.85	0.05
6	230	185	275		
		2004 year			
5	244	210	279	0.36	0.55
6	225	174	276		
		2005 year			
5	280	249	310	0.16	0.69
6	268	216	320		
		2006 year			
5	210	183	237	0.02	0.90
6	207	169	245		
		2007 year			
5	279	244	313	1.01	0.32
6	246.	191	301		
		2008 year			
5	238	204	271	0.34	0.56
6	219	165	274		
		2009 year			
5	250	222	277	0.57	0.45
6	229	176	282		
		2010 year			
5	172	148	195	0.24	0.63
6	160	116	205		

Note: * - statistically significant p<0.05 was observed, **F-test is a Fisher test (the critical value of the Fisher test is given in brackets). If the actual value of F is bigger than or equal to the critical (standard) value of F, the differences between the samples are statistically significant.

We investigated the effects of emissions in more detail and found that the significant differences in the growth of pine on poor and rich soils were detected only when the level of pollution is less than 6,000-10,000 tons. If contamination is above this level, the differences in growth are leveled. However, this pattern was not examined in certain years with weather factors (i.e., 1995, 1996 and

TABLE 5 Correlation analysis of factors influence on the level of differences in the radial growth of Scots pine growing on poor and rich soils.

Factor	Spearman correlation coefficient	P
Total air pollutants	0.63	0.006*
Gaseous air pollutants	0.57	0.016*
Average temperatures in May-August	0.64	0.005*
Average temperatures for June-August	0.41	0.099
Sum of positive temperatures	0.61	0.009*
Average monthly precipitation of the calendar year	-0.55	0.021*
Amount of precipitation in the calendar year	-0.55	0.021*
The average monthly precipitation of the growing year	-0.34	0.183
Average monthly precipitation from September of the previous year to August of the current year	-0.54	0.026*
Amount of precipitation from September of the previous year to August of the current year	-0.54	0.026*

2010). In 1995, there was a large emission to atmosphere of dust (KUZMINA and MENSCHIKOV, 2015). These emissions affected radial growth not only in 1995 but also in 1996. It should be noted that 2010 was very hot (ANONYMOUS, 1990b).

We performed a similar analysis for total air pollutants. The threshold values of total air pollutants were 25-30 thousand tons.

CONCLUSION

The comparative analysis of AGR of Scots pine plantations which grow on soils of various fertility, has allowed the estimation of the influence of the soil factor on ability of the Scots pine to adapt to technogenic (magnesite) pollution (Satka, Chelyabinsk region). The statistical reliability of differences in AGR of Scots pine was obtained. For the studied 17-year summer period (1994-2010) for 7 years AGR of the Scots pine, growing on fertile soils, were relatively higher than the pine growth on poor soils. It was revealed that, at the pollution level exceeding 6-10 thousand tons per year of gaseous emissions and 25-30 thousand tons per year of general emissions, the positive effect of fertility of soils on growth of Scots pine is leveled. The results obtained are of practical importance for reclamation of man-made landscapes.

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