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ORIGINAL PAPER

Growth of Scots pine (*Pinus sylvestris* L.) stands on soils with close bedding of crystalline parent rocks in Central Polissya, Ukraine

Sergii B. Kovalevskii[1] *, Anatolii Krol[1], Viktor Myroniuk[1], Serhii S. Kovalevskyi[1], Natalia Vysotska[2], Oleksandr Khromulyak[3], Vadym Yurchenko[4]

[1] *National University of Life and Environmental Sciences of Ukraine, 19 Heneral Rodimtsev Str., 03041 Kyiv, Ukraine*
[2] *Ukrainian Research Institute of Forestry and Forest Melioration named after G. M. Vysotsky, Kharkiv, Ukraine*
[3] *State Enterprise "Kiev Forest Research Station", Kiev, Ukraine*
[4] *State Enterprise "Lugansk Forest Melioration Research Station", Lugansk, Ukraine*

Abstract
The wide ecological range of Scots pine (*Pinus sylvestris* L.) demonstrates its ability to adapt to different environments. This study aimed to assess the dynamics of growth and productivity of Scots pine stands growing on soils with crystalline parent rock outcrops. The study area is located in the north of Ukraine in the Central Polissya within 50°15' and 50°06' north latitudes and 29°22' and 29°86' east longitudes. The base of the geological structure is granite. The depth of the parent rock bedding ranges from 15 to 86 cm. In total, 18 research plots were laid out on soils with crystalline rock outcrops and 18 research plots on sites with deep bedding of crystalline rocks (> 60 cm). To test the difference in stands growth within and outside sites with the crystalline outcrops, we used the Welch t-test. Pine forests on areas with deep bedding of parent rocks are systematically higher than those growing on sites with crystalline outcrops. With an increase of stand age, the difference between specified groups tends to be more significant. Stands growing on sites with and without crystalline rocks outcrops have similar dynamics, however, the latter ones accumulate more growing stock volume due to higher relative stocking, site index, mean diameter, and the number of trees. Our findings indicate the feasibility of establishing Scots pine stands in sites with different depths of the crystalline parent rocks bedding in Central Polissya, Ukraine.
Key words: Scots pine; granitic rocks; productive capacity; mathematical models; yield tables

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1. Introduction

Scots pine (*Pinus sylvestris* L.) is the most widespread species among conifers (Eckenwalder 2009) growing throughout Eurasia (Mátyás et al. 2004; Durrant et al. 2016). The wide ecological range of this species demonstrates its ability to adapt to different environments (Chertov et al. 1999; Socha 2008; Praciak et al. 2013; Pietrzykowski et al. 2015; Zadworny et al. 2017).

Scots pine stands play an important environmental and economic role in the Ukrainian forests (Vedmid et al. 2008). Most pine plantations are concentrated in the north, where the Plain Woodland is based on the Ukrainian shield (or Ukrainian Crystalline Massif). The precambrian crystalline rocks (anticlinoria, synclinoria, plutons) composing it often come to the surface. In general, the soil and climatic conditions of Polissya are favorable for pine stands. The most widespread here are infertile, fairly infertile, and fairly fertile sites with a variety of moisture conditions (Gordienko et al. 2006).

Soil conditions significantly affect the productivity of pine forests (Nieppola & Carleton 1991; Bravo-Oviedo & Montero 2005; Aertsen et al. 2012; Sharma et al. 2012; Pietrzykowski et al. 2015, 2019; Bueis et al. 2016). The interaction between the stand and the parent rock generates diverse growth dynamics (Migunova 2010). For example, soils with close bedding of granitic rocks or with their outcropping affect the structure of the root system of the trees (Kalinin et al. 1998).

In the Ukrainian Polissya, the influence of different soil types on the dynamics of Scots pine growth has been studied, for example, by Gordienko et al. (2006), Turko et al. (2007), Vedmid et al. (2008), Vishnevsky (2010). The authors found that the pine diameter growth in infertile sites is almost identical to that in fairly infertile sites in the first decades. The pine growth rate becomes higher in fairly infertile sites in older ages only (Kopiy

*Corresponding author. Sergii B. Kovalevskii, e-mail: s.kovalevsky@ukr.net
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& Mychajlenko 2008). In Central Polissya, pine stands on soils with close bedding of crystalline rocks were first established 100 years ago. These stands were proven to be productive (Kovalevskii & Krol 2018). Today, interest in the creation of pine forests for their reproduction and taking into account the resistance of Scots pine to changes in environmental factors, taking into account the high ecological plasticity of the species, does not decrease. Resolving this problem can provide the most balanced composition of pine stands in such conditions while maximizing ecological and resource value.

This study aimed to identify the differences in the growth and productivity of Scots pine stands growing on soils with close bedding of crystalline parent rocks and their outcrops in the Central Polissya.

2. Materials and methods

2.1. Study area

The study area and the permanent sample plots (PRP) are located in the north of Ukraine in Central Polissya within 50°15'and 50°06' north latitudes and 29°22 'and 29°86' east longitude, in Zhytomyr region (Fig. 1).

Geological and geomorphological features of the Central Polissya include lowland relief, sandy and loess deposits and dunes, swamps, a branched network of rivers with low rocky banks, outcrops of parent rocks, and glacial formations (fluvioglacial deposits and moraines) (Zamorii 1955).

The base of the geological structure is granite. The depth of the parent rock bedding ranges from 15 to 86 cm. The rocks often come to the surface of the soil as breakstones and boulders. Soils are acid with a low content of organic matter (humus), nutrients (NPK), and trace elements (Zn, Cu, Mn, Ni, B, Cr, Co). The most common are sod-medium podzolic loamy sand soils and sod-medium podzolic sand soils. Sod-podzolic loamy sand soils are characterized by low moisture capacity, high density, poor water retention, high water permeability, and deficiency in nutrients (Urkevich, 1969). The humus horizon thickness of sod-podzolic loamy sand soils is 14–16 cm on the plains, up to 10–12 cm on the hills, and up to 18 cm on the slopes.

2.2. Data collection and analyses

The rectangular research plots were established in the areas with and without crystalline rock outcrops. In total, 18 research plots were laid out on soils with crystalline rock outcrops and 18 research plots on sites with deep bedding of crystalline rocks (more than 60 cm). Research plot locations were identified by random sampling from



Fig. 1. The study area: a) location of the sample plots on a map of Ukraine; b) photo of typical Scots pine stand on soils with crystalline outcrops; c) close view of site with crystalline outcrops.

the total number of sites that met the requirements (the type of forest site conditions and age). Tree height (H), breast height diameter (D) ≥ 4 cm, the height of the beginning of live crown, and crown diameter in 4 directions perpendicular to each other were measured to determine actual stand characteristics. The heights were measured using a Vertex laser altimeter (Haglöf, Sweden) with an accuracy of 0.1 m.

We then grouped all data into 15-year age classes so that each group consisted of at least three observations. To test the difference in stand growth within areas of crystalline outcrops and without it we used the Welch t-test. This test is an adaptation of Students t-test which is recommended for groups comparison in case of data heteroscedasticity. The Welch t-statistic is calculated as follows:

$$t = \frac{m_A - m_B}{\sqrt{\frac{S_A^2}{n_A} + \frac{S_B^2}{n_B}}}, \quad [1]$$

where m_A, m_B – represent mean values of heights and diameters assessed for two groups of pine stands with and without crystalline rocks outcrops, respectively; n_A, n_B, – represent the number of sample plots within each group being compared, respectively; S_A^2, S_B^2, – standard deviation of the two groups, respectively.

The degrees of freedom for Welch t-test were estimated using equation [2]:

$$df = \frac{\frac{S_A^2}{n_A} + \frac{S_B^2}{n_B}}{\frac{S_A^2}{n_A^2 \cdot (n_B - 1)} + \frac{S_B^2}{n_B^2 \cdot (n_A - 1)}}. \quad [2]$$

Thus, we defined the null hypothesis $H_0 : m_{A,}$ and corresponding alternative hypothesis (H_a) was as follows: $Ha : m_A \neq m_B$. We used rstatix package for R statistical software to conduct this analysis (Myroniuk, 2020).

Site index is also an important indicator that determines the productivity of a forest depending on soil conditions. Up to the 1st class, the most productive ideas are given, up to the V – the least productive. The forest quality can be determined by the total timber stock or by its average growth. Still, the most common indicator of forest productivity is the average height of trees in the first layer of a forest plantation at a certain age. Knowing the average height and age of trees, the site index of a plantation was found according to the tables of quality classes.

3. Results

We found that pine forests on areas with deep bedding of parent rocks are systematically higher than those growing on sites with crystalline outcrops. The statistical difference at 95% significance level between mean stands height was identified for stands older than 25 years (Table 1). We found that the difference between specified groups tends to be more significant with an increase of age. Fig. 2a also indicates that within-group variance of height is higher for young and middle-aged stands than for pre-mature and mature ones. Similar results were obtained for mean stand diameter. However, the differences were not as significant as for stand height. For example, we found only one age group (70–84 age) for which the difference is significant at 95% level (p-value 0.031).

Table 1. Assessment of statistical difference in mean stands' heights and diameters using Welch t-test.

Age groups, ages	Height			Diameter		
	Student's t-statistic	Df	p-level	Student's t-statistic	df	p-level
10–24	1.64	3.93	0.177	1.53	3.95	0.202
25–39	2.89	3.72	0.049	1.76	4.00	0.153
40–54	3.86	2.49	0.043	2.28	3.32	0.099
55–69	9.39	3.76	0.001	2.42	3.27	0.067
70–84	8.76	3.33	0.002	3.54	3.42	0.031
85–99	11.7	4.00	0.000	2.11	3.92	0.104

We also evaluated site quality for sampled stands using site index curves which utilize the average height the dominant and codominant trees and their age. Thus, for areas with crystalline rock outcrops, the pine stands growth is usually characterized by I–II site index classes. The growth of pine stands established on soils with

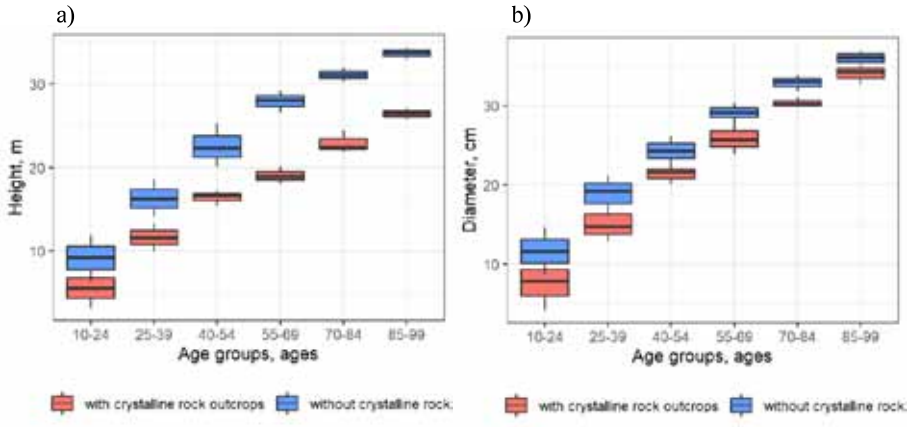


Fig. 2. Boxplot representing the difference in growth of pine stands in areas with and without crystalline rock outcrops: a) mean height; b) mean diameter.

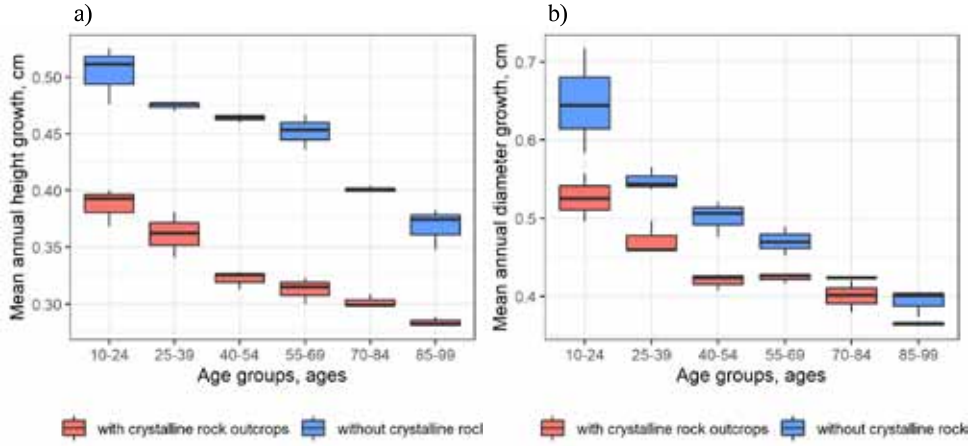


Fig. 3. Boxplot representing the difference in mean annual increment of pine stands in areas with and without crystalline rock outcrops: a) mean height; b) mean diameter.

deep bedding of crystalline rocks is faster and mostly described by I–Ia site index curves. Thus, crystalline rock is assumed to be a limiting factor for the growth of pine stands (Fig. 3).

Similarly to stand height and diameter we tested difference in rates of their mean annual growth using Welch t-test (Table 2). The differences are obvious for height increment, which persist for all analysed age groups. Although there are certain specifics in the growth of pine stands in areas with and without crystalline rocks outcrops, we revealed no statistically significant difference in mean annual diameter growth for stand ages of 70–84 and 85–99 years.

Table 2. Assessment of statistical difference in mean annual growth for stand height and diameter using Welch t-test.

Age groups, ages	Mean annual height growth			Mean annual diameter growth		
	Student's t-statistic	Df	p-level	Student's t-statistic	df	p-level
10–24	6.70	3.47	0.004	2.90	2.82	0.067
25–39	9.66	2.15	0.008	5.14	3.54	0.009
40–54	27.6	2.83	0.000	5.63	2.86	0.013
55–69	12.4	3.74	0.000	4.08	2.48	0.038
70–84	27.4	2.91	0.000	2.01	2.00	0.182
85–99	7.74	2.23	0.012	2.85	2.10	0.099

The relative stocking of pine stands decreases with age (Fig. 4). Pine stands of 10–24 years in study region are usually overstocked, while relative stocking of mature stands is only about 0.5–0.6.

4. Discussion

Soils are an important component in determining the sustainability and productivity of forest ecosystems because their properties influence the growth, development, composition, and structure of forest stands (Nambiar 1996; Chertov et al. 1999; Socha 2008; Afif-Khouri et al. 2010; Aertsen et al. 2012; Pietrzykowski et al. 2015). Mineral composition, particle-size distribution, density, porosity, structure, and chemical properties of parent rocks largely determine the direction of the soil-forming process and, accordingly, the soil fertility level (Raspopina 2009; Migunova 2010).

The growth and productive capacity of Scots pine are directly dependent on soil fertility, particle-size distribution, and moisture level (Nieppola & Carleton 1991; Mátyás et al. 2004; Gordienko et al. 2006; Bueis et al. 2016). The latter factor determines the survival ability, growth, and productivity of pine trees as a species capable of growing in rather extreme forest conditions (Zborovska 2014). Analysis of the state of pine planta-

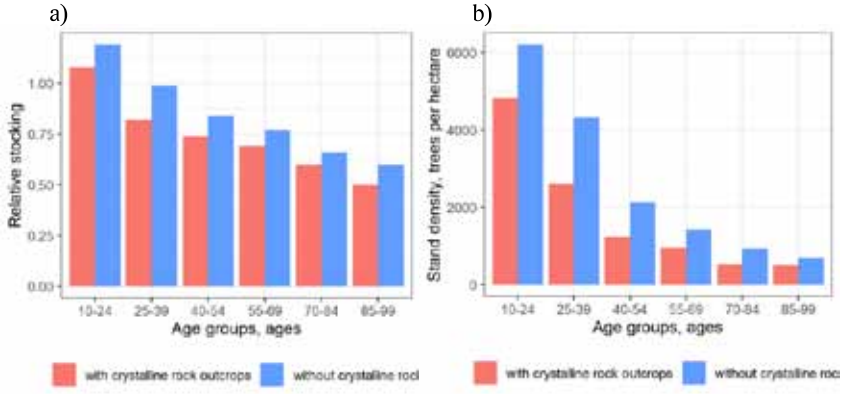


Fig. 4. Relative stocking (a) and density (b) of pine stands in areas with and without crystalline rock outcrops.

tions and growth patterns and productivity of pine stands in Central Polissya showed that this species could be grown most successfully in fresh fertile and fairly fertile forest site types (Gordienko et al. 2006; Turko et al. 2007; Vishnevsky 2010).

Important mensuration characteristics to determine the productivity of forests of any age are the mean height and diameter of the stands, their age, site class, the relative stocking, number of trees per hectare of area, etc. (Hrom 2007; Lakida et al. 2011). Combining these parameters makes it possible to determine whether the stand growth corresponds to the forest site conditions and identify influential environmental factors (Kopiy & Mychajlenko 2008). Our results show that, in terms of the productivity of Scots pine stands, sites with crystalline parent rock outcrops may be suitable for the growth of this species. In the absence of a solid layer of breakstones and stand-alone rocks, the roots can penetrate deeper soil horizons. It ensures the liveability of Scots pine trees, their intensive growth, and a high stock of stem wood per unit area.

Our analysis confirmed the effect of stand density on the development of Scots pine's crowns in sites with crystalline parent rock outcrops since it is known that the best light conditions for the accumulation of stem wood are essential in regulating the intensity of stand growth (Zborovska 2014).

5. Conclusion

Our analysis of the productivity of Scots pine stands in the sites with different depth of the crystalline parent rocks bedding indicate the feasibility of establishing Scots pine stands across a broad range of sites. At the same time, such sites have specific soil conditions and require differentiated management approaches fostering Scots pine productivity.

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