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Growth traits of natural regeneration of Scots pine (*Pinus sylvestris* L.) in south-eastern Poland

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Abstract

In recent years, particular attention has been paid to enhancing the meaning of natural regeneration, which is a part of the implementation of the concept of sustainable development and is one of the pillars of the natural direction of forest silviculture. Since the middle of the last century, the contribution of natural regeneration in Poland has been steadily increasing.

The paper presents the analysis of density and variability of growth traits of natural regeneration of Scots pine (*Pinus sylvestris* L.) in south-eastern Poland. The study involved four compartments, which were prepared with the use of tiller and plough (active and double mouldboard). Density of seedlings, their height and root collar diameter, were measured.

Density and growth characteristics of seedlings were higher at the tiller area and furrow compared with non-scarified soil and ridge. The highest cover with herbaceous plant was reported in ridges and non-scarified soil, but in most of the analysed compartments, it had no effect on the density of seedlings. It was found that different methods for soil preparation create different conditions for germination of seeds, which is reflected in the number of seedlings and its growth traits.

Key words

Scots pine, soil preparation, regeneration methods, seedlings growth

Introduction

In Europe, the type of forest trees regeneration through natural regeneration and natural expansion reaches 68%, while in South-West Europe is it 86% and in the Central-East Europe – 52%. The type of regeneration is also varied between the particular countries. For example, in the Czech Republic, natural regeneration and natural expansion is 2% of total renewal area, in Germany – more than 50%, in France – 75% and in Greece – 95% (State of Europe's Forests 2015). Most of the forest stands in Poland are regenerated artificially. In recent years, particular attention has been paid to enhancing the meaning of natural regeneration, which is a part of the implementation of the concept of sustainable development and is one of the pillars of the natural direction of forest silviculture (Hafemann 2004). Between 1976 and 1980, the contribution of natural regeneration in Poland was 3.4% of the total area dedicated for regeneration, while between 2001 and 2010, it increased to 10.4% (Kozioł and Matras 2011). Currently, it stands at 15.4% of removed forest

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areas and still growing. It results from a concern that artificial regeneration may limit genetic variability of forest trees. However, so far, this issue has not finally been resolved.

Scots pine is the main forest species in Europe. The range of occurrence of this species extends from longitude 8ºW in Spain to 14ºE in Russia and from latitude 70ºN to 37ºN (Andrzejczyk and Żybura 2012). Natural regeneration of Scots pine is used in coniferous forest habitats. However, in fertile and moist habitats, due to high competition of ground cover plants, it is recommended to use artificial regeneration (Hallikainen et al. 2007; Gabrilavicius et al. 2008). During the formation of natural regeneration, a key factor determining the success of regeneration is the choice of the proper method for soil preparation. The action relies on mechanical unveiling of the mineral layer on which seeds and seedlings are provided with adequate moisture and nutrient supplementation along with the elimination of competition from ground cover. The purpose of soil cultivation is to provide appropriate conditions for regeneration at the least possible violation of soil profile. For this purpose, a plough or tiller is used. In the literature, a few information can be found describing the effect of methodology of preparing the soil on the growth and survival of Scots pine seedlings in coniferous (Gmyz and Skrzyszewski 2010) and forest (Dobrowolska 2010) habitats, on the incidence of pests (Pihlaja et al. 2006; Sławska 2002; von Sydov 1997) and on growth of crops and young trees (Hansson and Karlman 1997). However, no clearly defined role of different soil cultivation methods in forest breeding and their impact on forest ecosystems has been determined (Pigan 2009; Zaricksson et al. 1997).

The aim of the study was to compare the effect of soil preparation on density and growth characteristics of natural regeneration of Scots pine. An attempt was also made to determine the differences of seedlings growing on ridge and furrow (plough-prepared soil) as well as tiller area and non-scarified soil (tiller-prepared soil). Two- and three-year crops were analysed. Growth characteristics of seedlings and the degree of coverage by herbaceous plants was assessed. The research hypothesis was that the method of soil preparation does not affect the growth of natural regeneration of Scots pine.

Material and methods

Study area

Studies on two- and three-year-old natural regeneration of Scots pine were carried out in the two compartments of Rozwadów and Janów Lubelski Forest District. Characterization of the research areas is presented in Table 1. All regenerations were obtained on fresh coniferous habitat with a mossy and bilberry cover and the average annual total rainfall ranging 600–650 mm. Considering cultivation in the Rozwadów Forest District, cutting area was characterized by a uniform coastal border, no old forest stand was maintained, while in Janów Lubelski Forest District, coastal border of cutting area exhibited antral course and bio-groups of old trees were maintained. The number of seed trees ranged from 52 to 90 (Tab. 1).

In July and August 2014, the growth of all crops was established for twelve evenly distributed sample surfaces, which were characterized by 10 × 10 m squares structure. Natural regeneration of Scots pine was evaluated separately on ridges, furrows, tiller areas and non-scarified soil. The following features of regenerations were characterized:

– density – expressed as the number of seedlings per m^2,
– height (cm),

Table 1. Characteristics of compartments in Rozwadów and Janów Lubelski Forest Districts

Localization	Age of regeneration	Compartment	Soil	Method of soil preparation	Number of seed trees preserved
Rozwadów Forest District	2 years	168b	Bw, pl	LPZ-75 double-mouldboard plough	90
		238a	RDb, pl	tiller	82
Janów Lubelski Forest District	3 years	266b	RDb, pl	tiller and active plough	52
		267a	RDb, pl	tiller and active plough	78

RDb – brown poolsolic soil, Bw – brown soil, pl – sandy loam

– root collar diameter (mm),
– degree of coverage with herbaceous plants (class 1: up to 25%, class 2: 26–50%, class 3: > 51%),
– degree of regenerations damage (class 1: up to 25%, class 2: 26–50%, class 3: > 51%).

Data analysis

The influence of soil preparation on density, height and r root collar diameter of seedlings, separately for two- and three-year-old regenerations, was determined by one-way analysis of variance (ANOVA). Tukey test ($p = 0.05$) was used as the post-hoc test. To evaluate the relationship between the density of seedlings and the cover with herbaceous plant, Spearman correlation test was used. Calculations were performed using Statistica ver. 13.1 (StatSoft Inc. 2017).

Results

All traits (density, height, root collar diameter) were characterized by generally higher values on the tiller area and furrow compared with non-scarified soil and ridge. This pattern was clearly underlined in terms of the density, which was confirmed by the results obtained based on the analysis of variance and post-hoc test (Tab. 2). In each compartment, the number of Scots pine seedlings per m^2 of furrow and tiller area was significantly different from that reported in the area of non-scarified soil and ridge.

In terms of the root collar diameter, Tukey's test classified the two-year-old Scots pine regenerations into three homogeneous groups (Tab. 3). Similarly, as for the previous characteristics, Scots pine growing on tiller area and furrows were significantly different from each other and from the remaining regenerations growing on non-scarified soil and ridge. Three-year-old seedlings were divided into two homogeneous groups. The lowest root collar diameter was observed for Scots pines growing on non-scarified soil, while the differences between the regeneration occurring in the tiller area as well as furrow and ridge were statistically insignificant.

Table 2. Average parameters of pine density on two- and three-year crops; the homogeneous group includes a Tukey test for p = 0.05

Regeneration age	F-test (significance level)	The method of soil preparation	Density [number per m^2]
2 years old	47.95 ($p < 0.0001$)	non-scarified soil	1.39 ± 0.61^{a}
		ridge	1.86 ± 1.31^{a}
		furrow	4.25 ± 1.34^{b}
		tiller area	8.24 ± 2.43^{c}
3 years old	46.12 ($p < 0.0001$)	non-scarified soil	0.95 ± 0.34^{a}
		ridge	2.51 ± 1.47^{a}
		furrow	8.31 ± 2.81^{b}
		tiller area	10.87 ± 3.61^{b}

Table 3. Average parameters of root collar diameter on two- and three-year crops; the homogeneous group includes a Tukey test for p = 0.05

Regeneration age	F-test (significance level)	The method of soil preparation	Root collar diameter [mm]
2 years old	29.62 ($p < 0.0001$)	non-scarified soil	3.07 ± 1.01^{a}
		ridge	3.22 ± 1.04^{ab}
		furrow	3.56 ± 1.19^{b}
		tiller area	4.28 ± 1.18^{c}
3 years old	7.03 ($p < 0.0001$)	non-scarified soil	8.59 ± 4.05^{a}
		ridge	9.80 ± 3.06^{b}
		furrow	10.30 ± 2.92^{b}
		tiller area	10.53 ± 4.14^{b}

Table 4. Average parameters of growth on two- and three-year crops; the homogeneous group includes a Tukey test for p = 0.05

Regeneration age	F-test (significance level)	The method of soil preparation	Height [cm]
2 years old	48.30 ($p < 0.0001$)	non-scarified soil	9.46 ± 2.41^{a}
		ridge	10.64 ± 3.32^{b}
		furrow	11.80 ± 2.41^{b}
		tiller area	13.79 ± 3.29^{c}
3 years old	19.88 ($p < 0.0001$)	non-scarified soil	32.02 ± 7.26^{a}
		ridge	34.18 ± 8.22^{a}
		furrow	38.22 ± 8.31^{b}
		tiller area	38.92 ± 8.48^{b}

Moreover, regenerations differed significantly in terms of height. All pines were divided into three homogeneous groups, however, their distribution in two- and three-year-old regenerations was different (Tab. 4). A common feature combining the two age groups was the phenomenon that on tiller area and furrow, individuals were significantly higher than on non-scarified soil and ridge, respectively.

On all surfaces, regardless of regeneration age, the cover with herbaceous plant was higher on ridges and non-scarified soil than in deeper located furrows and tiller areas. This pattern was more clearly underlined in terms of crops, which were growing on the soil prepared with tiller (Fig. 1). Despite that, a significant correlation between the number of seedlings and the degree of the cover with herbaceous plant, was observed only in 238a compartment and was equal to −0.504 ($p = 0.05$). The degree of damage of Scots pine was similar in all compartments. However, in most cases, regenerations were more damaged on areas located in the soil cavities (Fig. 1).

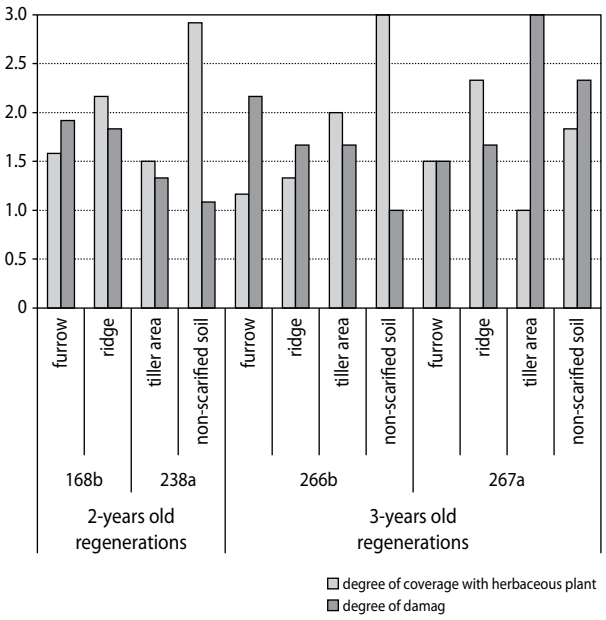

Figure 1. The degree of coverage with herbaceous plants and the degree of damage of two- and three-year-old regenerations of Scots pine, depending on the soil preparation methodology

Discussion

In the present study, the quality of natural regenerations were analysed, which were growing on the soil that was prepared with tiller and the plough (LPZ-75 double-mouldboard and active). The conducted studies showed high level of abundance of two- and three-year-old pine regenerations. According to the valid Principles of forest cultivation (2012), in Poland, the seedlings are introduced artificially within the range of 8–10 thousand seedlings per 1 ha of crop. Forest culture from natural regeneration is recognized if the number of growing seedlings is not less than 20 individuals per m^2. In our studies in terms of forest plough and tiller, these were similar and accounted for 30 and 33 thousand specimens per 1 ha of crop, respectively. However, in the three-year-old crops with different methodology of soil preparation, the number of seedlings exceeded 80 thousands per 1 ha.

In both age groups, density pattern of seedlings was similarly distributed. Most individuals occurred on tiller prepared soil while the least on non-scarified soil. Comparing the compartments investigated, there was a clear trend, that much more seedlings occurred on surfaces with older seedlings. Since the two- and three-year-old regenerations were growing under similar habitat conditions, this difference can presumably be explained by greater abundance of seeds in sowing year. This pattern did not affect only the not-scarified soil. On the soil that was not prepared for seeds germination, less than one seedling per m^2 of the surface was observed. It is possible that in a few years' time only single individuals will remain. The main reason for such a low density of seedlings on the soil, which was not subjected to any scarification activity, can be a large degree of cover with herbaceous plant, which affects survival and growth of pine individuals during the early stages (Jaworski, 2011). According to Gmyz and Skrzyszewski (2010), the main species limiting the growth of seedlings is bilberry (*Vaccinium myrtillus* L.), which is the main component of the ground cover on the cover of mossy and bilberry, where it forms dense field. Since this species sheds its leaves in winter, it contributes in this way to the thickening the moor layer Pearson correlation test demonstrated the strongest and statistically significant relationship between the degree of cover with herbaceous plant and the density of seedlings only

in 238a compartment, in which the soil was prepared only with the use of tiller. It seems that the soil prepared with the plough and tiller effectively eliminates the presence of a thick layer of putrescent debris and effectively destroys weeds.

Soil preparation in combination with large seed production and suitable weather conditions enables successful pine regeneration (Grigoriadis et al. 2014) and the greatest success was on fresh coniferous habitat (Długosiewicz et al. 2019). Under the conditions analysed in our study, preparation of soil seems to be a necessary procedure for the natural regeneration of Scots pine trees. Scarification alone may be carried out with tools, which differently modify the top layer of soil. Seedling density, height and root collar diameter were significantly different not only on the surfaces prepared with tiller, double-mouldboard plough and active plough, but also between differently-shaped areas of soil. The obtained results indicate, that the best conditions were maintained on soil prepared with tiller. In both age groups, the most seedlings were observed there and they were also characterized by the highest values of height and root collar diameter. Moreover, regenerations growing in the furrows, which were formed as a result of the use of both types of plough, were characterized by quite high values of features analysed, however, in most cases, they were lower in comparison to those observed on tiller areas. According to Sewerniak et al. (2017), the tiller gives better growth conditions than the plough, because it allows to maintain higher humidity. However, the situation changes in drought conditions. Different results were obtained by Sewerniak et al. (2012), who reported that during two years of the study, regeneration of Scots pine trees were thicker and higher on the surfaces with soil prepared with the use of LPZ plough. The authors explain such a result by soil and climatic conditions. Seedlings growing on the tiller areas, wherein the content of humus is twice higher than on the soil prepared with plough as a consequence of mixing the top soil cover with mineral layer, are characterized by decreased development of the root system. In Puszcza Bydgoska, located in the areas with highly decreased total annual rainfall, seedlings are exposed to stress associated with water depletion. It results in poorer soil wettability with higher humus content (Prusinkiewicz 1979). Moreover, Andrzejczyk and Żybura (2012) indicated the problem of water depletion on light soils after milling. It seems that within the areas of Janów Lubelski and Rozwadów Forest Districts, rainfalls at the level of 600–650 mm ensure the regeneration of adequate soil moisture, so that seedlings growing on the tiller area can fully use fertile layer of humus.

The function of plough is based on ploughing of furrows, from which humus layer and part of the mineral soil are taken off and removed on the ridge (Andrzejczyk and Augustyniak 2007). It results in different soil conditions in the furrow and ridge. In the furrow, mineral soil fertile layer is unveiled, in which water soaking provides favourable moisture conditions for seed germination. In contrast, the ridge constitutes a convex area, as here, the top layer is additionally covered by turf and moor layer, which are easily subjected to dryness as no water soaking is observed there (Andrzejczyk and Drozdowski 2003), which is confirmed by the works of Czeżyk (2017) and Korzeniewicz et al. (2016) who studied the impact of soil preparation on the density of pine regeneration. Moreover, for the benefit of seeds' germination in the furrow is the fact, that, as a result of blowing away, they accumulate in cavities in larger quantities. The studies conducted by Andrzejczyk and Drozdowski (2003) demonstrate, that after preparation of soil with double-mouldboard plough, 70–80% of the seeds germinate in the furrows, however, due to higher mortality of seedlings, after several years of growth on fresh coniferous forest habitat, their number on both areas become similar. In addition, the difference in the value of biometric features in favour of regenerations growing on ridges, was already evident at the annual (Andrzejczyk and Twaróg 1998) and two-year-old seedlings (Andrzejczyk and Drozdowski 2003). On habitats that were poor and not vulnerable to intensive weed infestation, Andrzejczyk and Augustyniak (2007) recommend the use of active plough, as it produces more shallow furrows and interferes in the soil with low humus content to a lesser extent. In studies by Czeżyk (2017), it was found that seedlings in furrows are higher than on ridges. In Rozwadów and Janów Lubelski Forest Districts, the regenerations were characterized by higher, generally statistically significant, values of all analysed traits in the furrows, regardless of age and type of plough used. It can therefore be assumed, that seedlings assessed in our work did not consume min-

eral resources of the exposed soil in the furrows and their preponderance will continue in the longer term.

Germination of seeds in temperate climates depends mainly on the condition of soil cover (Andrzejczyk 2002; Hafemann 2004; Hille and Ouden 2004). According to Andrzejczyk and Żybura (2012), the most important factors affecting germination and growth of Scots pine seedlings are temperature and moisture of the soil. Moreover, a barrier for obtaining the regeneration is too thick humus layer. With mor characterized by a thickness up to 3 cm, roots of seedlings are able to reach mineral soil layer, in which, they have an adequate moisture and nutrient content. However, 5 cm humus layer completely eliminates the possibility of natural regeneration (Gmyz and Skrzyszewski 2010). Therefore, an important action and in many habitats, and a necessary one, is the appropriate soil preparation. Although some authors suggest the possibility of soil cultivation omission (Dong et al. 2003), most studies confirm that each previously used method of soil cultivation in forestry, provides more pine self-seeding in comparison to the number that occurs on non-prepared soil (Drozdowski 2002).

Conclusions

Natural regeneration of Scots pine was characterized by high density and high variability of growth traits both between the examined compartment and between differently shaped soil strips. One of the highest growth conditions were found on the tiller area and on the furrows, and the worst on the ridge and non-scarified soil. It can therefore be assumed that seed germination and subsequent dense and growth characteristics of pine were affected only by different status of soil cover preparation. Appropriate method for soil preparation modifies the environment of seeds germination in the first growth phase. The method of soil preparation did not affect both the degree of damage to seedlings and the degree of coverage with herbaceous plants.

However, it should be noted that the results of research in other climatic conditions or a different development phase may be different. Therefore, it is necessary to conduct further research in the older stages of the stand development.

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